Recommended Priorities for Geomorphology Research in Endangered Fish Habitats of the Upper Colorado River Basin

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RECOMMENDED PRIORITIES FOR GEOMORPHOLOGY RESEARCH IN ENDANGERED FISH HABITATS OF THE UPPER COLORADO RIVER BASIN

prepared by

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EXECUTIVE SUMMARY

Activities of the Upper Colorado River Endangered Fish Recovery Program (Recovery Program) include habitat improvement and management (e.g., restoration of flooded bottomlands, provision of fish passage) and flow management to provide suitable habitat conditions for the four species of endangered fishes in the Upper Colorado River Basin — Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), bonytail (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*). In this report, we identify and apply an approach for prioritizing river reaches and habitats for geomorphic research in the Upper Colorado River Basin.

The goal of this project was to identify priorities for geomorphology research in endangered fish habitats of the Upper Colorado River Basin. These recommended priorities provide input to the Recovery Program as it develops a comprehensive research and monitoring program for endangered fish habitats. Project objectives included:

- Review and consolidate geomorphic, habitat, and flow information;
- Identify relationships among flow regimes, habitats, fish needs, and recovery goals; and
- Identify data gaps and rank their importance to recovery.

The report focuses on the reaches and habitats used by life stages (larvae, juveniles, subadults, adults, and spawning) of three of the four species — the Colorado pikeminnow, humpback chub, and razorback sucker. Insufficient information was available on the bonytail to permit a meaningful evaluation. The evaluation includes the Green River between Flaming Gorge Dam and its confluence with the Colorado River and the upper Colorado River upstream of the headwaters of Lake Powell. Major tributaries of these two rivers, up to the point of occupation by endangered fishes, also were included.

We developed a linked-matrix approach to systematically and objectively identify overall priorities for research. Spreadsheets were developed that contained scores (0, 1, 2, or 3) to represent relative importance of (1) existing reach use for species and life stages, (2) habitat use for species and life stages, (3) habitat occurrence within planform types, and (4) dependencies between habitat characteristics and hydrologic and geomorphic parameters. Scores also were assigned to life stages and species on the basis of sensitivity to environmental variability and population status, respectively. These scores enabled weighting of life stages and species when scores were combined to determine overall priorities. Weights were applied in a phased manner that enabled consideration of priorities at various levels, including (1) species-life stage, (2) species, and (3) all species combined. Scores were developed during two workshops attended by researchers from various agencies, consulting firms, and universities.

The Upper Colorado River Basin was subdivided into the Green River subbasin and the upper Colorado River subbasin. Each major river was divided into reaches based on the dominant geomorphic planform (restricted meander, fixed meander, and canyon). These planforms describe various levels of confinement of the river channel within the surrounding geology, which in turn affects habitat characteristics relevant to endangered fishes. Restricted meanders occur in broad alluvial terraces that are bounded by relatively more resistant geology. Fixed meanders are confined by resistant geology on both outside and inside bends of the main channel. Canyons consist of relatively straight sections of river with resistant geology on both sides of the river. Habitat types considered included pools, runs, riffles/rapids, connected backwaters, side channels, eddies, flooded tributary mouths, and flooded bottomlands.

Consideration also was given to potential use of reaches, assuming improvements in conditions in response to implementation of flow recommendations, planned removal of existing barriers to passage, and successful establishment of populations through augmentation. Consideration of potential reach use was considered especially important for the razorback sucker in the upper Colorado River subbasin, because existing levels of use are so low and so few larvae and juveniles exist in the system.

Once we computed reach-habitat scores and scored the dependence of habitat characteristics on hydrology and geomorphology, we searched the available literature for studies that addressed important parameters in the highest scoring reaches and habitats. Remaining information needs were those important relationships in priority reaches and habitats that had not been addressed by previous studies.

In the Green River subbasin, the highest overall reach-habitat scores for species and life stages combined are in the Split Mountain Canyon to Desolation Canyon reach. Habitats with high scores in this restricted-meander reach include connected backwaters, side channels, flooded tributary mouths, and flooded bottomlands. All are low-velocity habitats that serve as critical nursery areas for Colorado pikeminnow and razorback suckers.

The extremely dynamic nature of backwater and side-channel habitats demands a greater understanding of the geomorphic processes that form and maintain those habitats. Additional research is needed to verify the existing conceptual model of backwater formation and more fully understand underlying geomorphic processes, including the effects of antecedent conditions. Studies are also needed to address the effects of base-flow variability (inter-annual, intra-annual, and within day) on backwater and side-channel habitat availability and conditions.

Scores were high for spawning bar complexes in the Desolation and Gray Canyons reach and in the Yampa Canyon reach because several species spawn in each. Studies are needed of spawning bars in the Split Mountain Canyon to Desolation Canyon reach and in Desolation and Gray Canyons to determine the effects of peak flow, base flow, and sediment characteristics on the formation and maintenance of suitable spawning habitats. Although several studies have examined geomorphic properties of the razorback spawning bar in the Split Mountain Canyon to Desolation Canyon reach, additional study is needed to verify the existing conceptual model for this bar and better understand the effects of peak-flow magnitude, peak-flow duration, peak-flow frequency, peak-flow timing, and sediment on habitat conditions during the spawning period.

Several studies have examined the underlying geomorphic processes that affect the formation and characteristics of backwaters and side channels in the upper Colorado River upstream of Westwater Canyon, and focused on the effects of a few high-water years in the 1990s. It is important to study flow-habitat relationships in more years and to determine the role of peak-flow magnitude, duration, frequency, and variability on habitat maintenance. In addition, geomorphic processes affecting backwaters in the Moab Bridge to Green River reach have not been studied, and the processes identified for the gravel-bedded upper river would not apply to this sand-bedded reach. As for the Green River, additional studies of backwater availability need to be conducted because of the dynamic nature of this habitat.

No studies have been conducted of spawning habitat in any reach in the upper Colorado River subbasin because spawning apparently is not concentrated in a few areas as it is in the Green River subbasin. However, studies of spawning habitat and the underlying geomorphic processes that affect availability and characteristics during the spawning season are critically needed. Studies should focus on identifying suitable spawning habitats and determining the effects of peak flow, base flow, and sediment characteristics on spawning habitat.

We suggest that reach-habitat priorities based on existing levels of reach use be used wherever possible to avoid the uncertainties associated with potential use. However, the population status of razorback suckers in the upper Colorado River subbasin and barriers to fish passage in the upper river reduces the value of using existing use patterns in developing priorities for geomorphic research. Consequently, we recommend basing prioritization on potential reach use for the upper Colorado River subbasin. As the status of populations change in response to management actions, including stocking, habitat improvements, and reconnection to historic habitat, priorities for the upper Colorado River subbasin should be reconsidered.

We recommend a phased, integrated approach to implementation of the research priorities identified in this report. Primary information needs for overall reach-habitat priorities should be considered the highest priorities for research because research on these topics and reaches has the potential to have the largest benefit to recovery of the endangered fishes. Consideration should also be given to those primary species-specific information needs. Primary information needs for overall reach-habitat priorities in the Green River and upper Colorado River subbasins include:

Green River Subbasin (based on existing conditions in the subbasin)

1. Connected backwaters and side channels (Split Mountain Canyon to Desolation Canyon and Labyrinth and Stillwater Canyons)
    - Role of peak flow (magnitude, duration, and frequency) and sediment on formation and maintenance of habitats.
    - Effects of antecedent conditions (flow and sediment) and base-flow magnitude on habitat availability.
    - Effects of base-flow variability on inter-annual availability, intra-annual stability, and within-day stability.

2. Flooded bottomlands (Split Mountain Canyon to Desolation Canyon)
    - Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects.
3. Spawning bar complexes (Desolation and Gray Canyons)
    - Effects of peak flow (magnitude, duration, frequency, and timing), base flow (magnitude and duration), and sediment on habitat conditions during the spawning period.

Upper Colorado River Subbasin (based on potential conditions in the subbasin)

1. Connected backwaters and side channels (Moab Bridge to Green River)
    - Same as those identified for Split Mountain Canyon to Desolation Canyon reach of the Green River.
2. Flooded bottomlands (Palisade to Gunnison River and Gunnison River to Loma)
    - The relationship of habitat availability to peak-flow and base-flow magnitude.
    - Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects.
3. Flooded bottomlands (Gunnison River—Hartland Dam to Roubideau Creek)
    - Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects.
4. Spawning bar complexes in the Colorado River (Palisade to Gunnison River, Gunnison River to Loma, and Loma to Westwater) and Gunnison River (Hartland Dam to Roubideau Creek, Roubideau Creek to Colorado River)
    - Location and characteristics of spawning habitats.
    - Effects of peak flow (magnitude, duration, frequency, and timing), base flow (magnitude and duration), and sediment on habitat conditions during the spawning period.

Primary information needs to address species-specific reach-habitat priorities include:

Green River Subbasin (based on existing conditions in the subbasin)

1. Colorado Pikeminnow
    a. Connected backwaters and side channels (Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, Labyrinth and Stillwater Canyons)
        - Same as those identified for Split Mountain Canyon to Desolation Canyon reach under overall reach-habitat priorities above.

   b. Spawning bar complexes (Desolation and Gray Canyons)

      - Same as those identified for Desolation and Gray Canyons reach under overall reach-habitat priorities above.

2. Humpback Chub

   a. Spawning bar complexes (Desolation and Gray Canyons)

      - Same as those identified for Desolation and Gray Canyons reach under overall reach-habitat priorities above.

3. Razorback Sucker

   a. Spawning bar complexes (Split Mountain Canyon to Desolation Canyon)

      - Same as those identified for Desolation and Gray Canyons under overall reach-habitat priorities above.
      - Location of additional potential spawning areas in reach.

   b. Flooded bottomlands (Split Mountain Canyon to Desolation Canyon)

      - Same as those identified for Split Mountain Canyon to Desolation Canyon reach under overall reach-habitat priorities above.

Upper Colorado River Subbasin (based on potential conditions in the subbasin)

1. Colorado Pikeminnow

   a. Connected backwaters and side channels (Cottonwood Wash to Dewey Bridge, Jackass Canyon to Moab Bridge, Moab Bridge to Green River)

      - Same as those identified for connected backwaters in Split Mountain Canyon to Desolation Canyon reach of the Green River under overall reach-habitat priorities above.

   b. Spawning bar complexes in the Colorado River (Palisade to Gunnison River, Gunnison River to Loma, Loma to Westwater, Cottonwood Wash to Dewey Bridge) and Gunnison River (Hartland Dam to Roubideau Creek, Roubideau Creek to Colorado River)

      - Same as those identified for spawning bar complexes in upper Colorado River subbasin under overall reach-habitat priorities.

2. Humpback Chub

   a. Spawning bar complexes (Loma to Westwater Canyon—Black Rocks portion, Westwater Canyon)

      - Same as those identified for spawning bar complexes in upper Colorado River subbasin under overall reach-habitat priorities.

3. Razorback Sucker

   a. Flooded bottomlands (Palisade to Gunnison River, Gunnison River to Loma, Gunnison River—Hartland Dam to Roubideau Creek)

- Same as those identified for flooded bottomlands in upper Colorado River subbasin under overall reach-habitat priorities above.

b. Spawning bar complexes in the Colorado River (Palisade to Gunnison River, Gunnison River to Loma, Moab Bridge to Green River) and Gunnison River (Hartland Dam to Roubideau Creek).

- Same as those identified for spawning bar complexes in upper Colorado River subbasin under overall reach-habitat priorities.

c. Connected backwaters and side channels (Moab Bridge to Green River)

- Same as those identified for connected backwaters in Split Mountain Canyon to Desolation Canyon reach of the Green River under overall reach-habitat priorities above.

One aspect of a phased, integrated approach is selection among the identified information needs. For instance, rather than attempting to determine the geomorphic basis of spawning habitats in all nine of the identified high-priority reaches of the upper Colorado River subbasin simultaneously, research should focus on a limited subset of representative spawning areas in one or a few of these reaches. Reaches should be selected for further study on the basis of the results of initial studies to identify and characterize spawning habitats in the subbasin. As relationships among flow, geomorphology, and habitat characteristics are determined in representative study reaches, results can be verified in other high priority reaches.

All research of geomorphic processes and habitats should be based on hypothesis testing. We recommend that, whenever possible, studies incorporate experimental manipulations and the testing of predicted responses. We also recommend standardization of research protocols and data collection techniques. It is important to recognize that these recommendations are based on current understanding of habitat requirements and geomorphic processes. It is likely that adjustments to research priorities will be necessary as the research proceeds, and, indeed, the success of the effort will require such adaptation as new information is obtained and inferences are drawn. The research priorities identified in the report are recommendations based on data needs and their importance to recovery. Ultimately, the Recovery Program will determine the direction of future research, and multiple factors (including, but not limited to those considered in this report) will be considered in those determinations.

List of Keywords

Geomorphology, hydrology, habitats, research priorities, Colorado pikeminnow, humpback chub, razorback sucker, flooded bottomlands, connected backwaters, spawning bars, Upper Colorado River Basin, Green River subbasin, upper Colorado River subbasin

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NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this report.

ABBREVIATIONS

BW	backwater(s)
FTM	flooded tributary mouth(s)
FB	flooded bottomland(s)
Recovery Program	Upper Colorado River Endangered Fish Recovery Program
SBC	spawning bar complex(es)
SC	side channel(s)
UDWR	Utah Division of Wildlife Resources
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

UNITS OF MEASUREMENT

cfs	cubic foot (feet) per second
in.	inch(es)
km	kilometer(s)
m^3	cubic meter(s)
mi	mile(s)
mm	millimeter(s)
rkm	river kilometer(s)
rm	river mile(s)
s	second(s)
yr	year(s)

PRIORITIES FOR GEOMORPHOLOGY RESEARCH IN ENDANGERED FISH HABITATS OF THE UPPER COLORADO RIVER BASIN

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1 INTRODUCTION

Activities of the Upper Colorado River Endangered Fish Recovery Program (Recovery Program) include habitat improvement and management (e.g., restoration of flooded bottomlands, provision of fish passage) and flow management to provide suitable habitat conditions for the four species of endangered fishes in the Upper Colorado River Basin — Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), bonytail (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*). Flow recommendations have been or are being developed for the major rivers in the Upper Colorado River Basin. An important premise behind the use of flow management as a recovery tool is that links between flow and geomorphic processes can be used to provide, augment, and enhance habitats used by the various life stages of the endangered fishes.

Recovery goals were recently developed for the four species (U.S. Fish and Wildlife Service [USFWS] 2002a-d), and these goals require that habitats needed to support recovered populations be identified, provided, and protected. While the habitat needs of the Colorado pikeminnow, humpback chub, and razorback sucker are generally understood, there are uncertainties associated with our level of understanding of the processes of habitat formation and maintenance, and, therefore, uncertainties that adherence to any specific flow recommendations will ensure provision of suitable habitat conditions in the future. It is clear that additional geomorphic research is needed to provide a reasonable level of certainty that flow management can be used to provide the needed habitats for the endangered fishes.

Research directed toward development of a better understanding of the relationships between geomorphic processes and habitats has been conducted and funded by the Recovery Program since its inception. Although past studies have added to the Recovery Program's overall body of knowledge, the need exists to systematically identify information needs and prioritize future research to address those needs. Therefore, the Recovery Program postponed funding of new geomorphic research until research priorities could be established.

The goal of this project was to identify priorities for geomorphology research in endangered fish habitats of the Upper Colorado River Basin. These recommended priorities provide input to the Recovery Program as it develops a comprehensive research and monitoring program for endangered fish habitats. Project objectives included:

- Review and consolidate geomorphic, habitat, and flow information;

- Identify relationships among flow regimes, habitats, fish needs, and recovery goals; and

- Identify data gaps and rank their importance to recovery.

Any prioritization of future research must consider the relative importance of research topics as well as the subjects addressed and the adequacy of previous research. In this report, we develop and implement an approach to determine high priority river reaches and habitats for geomorphic research in the Upper Colorado River Basin (Figure 1). In addition, we provide an overview of previous research and sort this research by location and topic to help identify information gaps. The report does not identify specific, detailed research needs, but rather identifies topic areas and processes in reaches and habitats that should be addressed by research. It will be up to future investigators to develop the detailed research plans to implement field studies needed by the Recovery Program.

Only the Colorado pikeminnow, humpback chub, and razorback sucker were considered in this evaluation. The bonytail was not included because wild bonytail have been extirpated from the Upper Colorado River Basin and very little is known about the species. Consequently, consideration of the bonytail at this time would not provide valuable input for establishing geomorphic and habitat research priorities. Efforts are underway to reintroduce bonytail into the Upper Colorado River Basin. As information on the habitat needs of the species is obtained, additional research needs should be considered. However, it is likely that consideration of the needs of the Colorado pikeminnow, humpback chub, and razorback sucker would encompass the needs of the bonytail as well.

The geographic scope of the evaluation includes the Green River between Flaming Gorge Dam and its confluence with the Colorado River and the upper Colorado River upstream of the headwaters of Lake Powell (Figure 1). Major tributaries of these two rivers also were included in this evaluation.

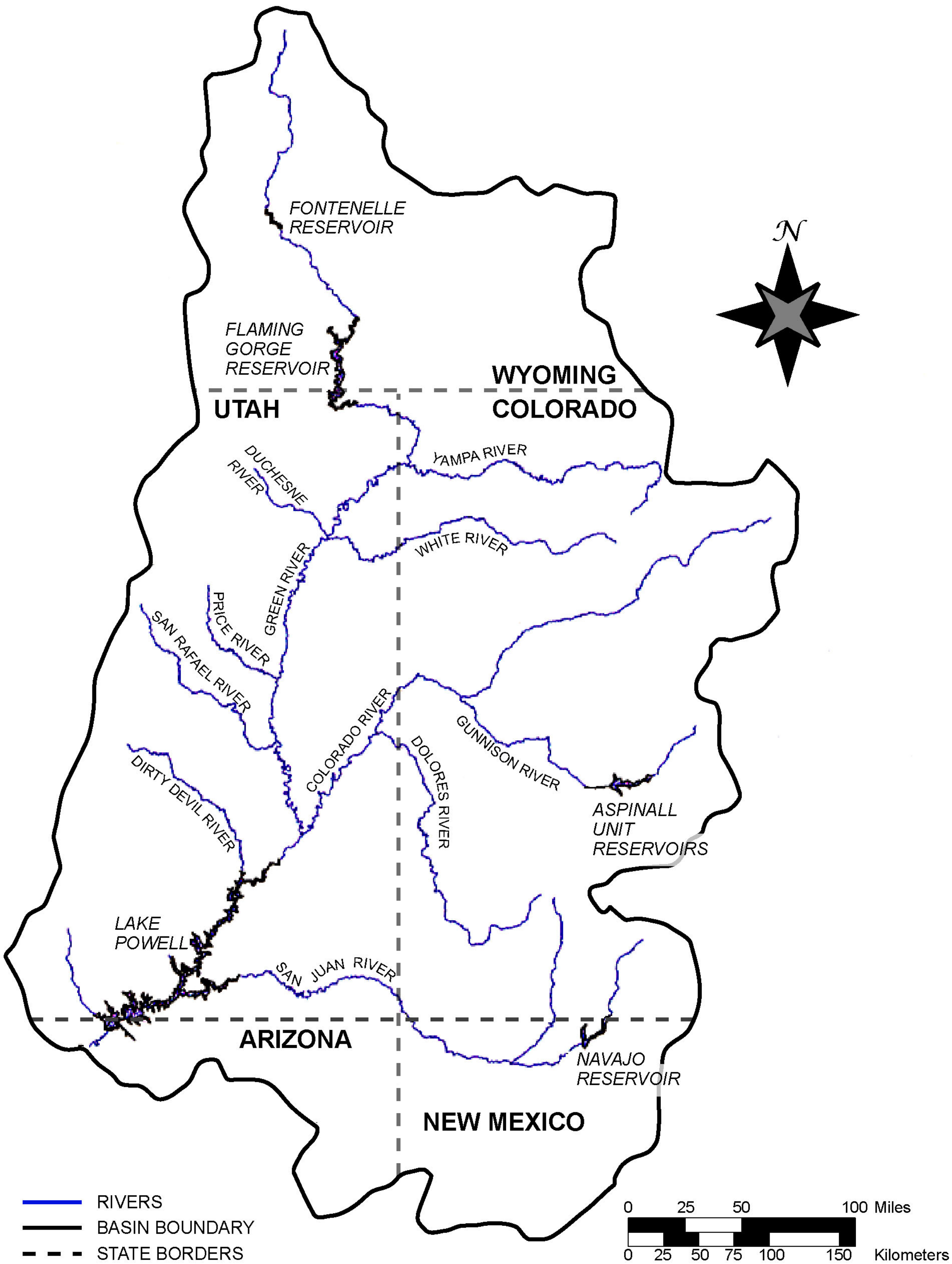

Figure 1. Map of the Upper Colorado River Basin.

2 LIFE HISTORIES OF COLORADO PIKEMINNOW, HUMPBACK CHUB, AND RAZORBACK SUCKER

This section provides a brief overview of the life histories, distributions, and population status of the Colorado pikeminnow, humpback chub, and razorback sucker. In addition, information is provided on important habitat[1] requirements of these species and geomorphic processes that form and maintain these habitats.

2.1 COLORADO PIKEMINNOW

The endangered Colorado pikeminnow is endemic to the Colorado River Basin and was formerly widespread and abundant in warm-water streams and rivers of the basin (Jordan and Evermann 1896). Large populations of Colorado pikeminnow were reported in the upper Colorado River subbasin in historic accounts (Tyus 1991; Quarterone 1993). Colorado pikeminnow persist in all three major river and tributary systems of the upper basin (i.e., San Juan, upper Colorado, and Green River subbasins), but populations are severely reduced in all but the Green River (Platania et al. 1991; Tyus 1991; Osmundson and Burnham 1996). Total population size has been estimated at between 6,600 and 8,900 adults; most of these (6,000 to 8,000) are in the Green River (USFWS 2002a).

The distribution and abundance of Colorado pikeminnow in the rivers of the upper basin have been adversely affected by such factors as construction and operation of dams, reductions in flows, and the introduction of nonnative fishes. Flaming Gorge Dam altered the distribution and status of Colorado pikeminnow in the Green River and for the most part eliminated them from areas upstream of the Yampa River confluence. Three dams located on the Colorado River upstream of Palisade, Colorado, have similarly restricted upstream movement of fish for more than 80 years. Although there are no observations on record to verify recent or historic use of reaches upstream of DeBeque, Colorado, there is at least one anecdotal account that suggests possible use as recently as the early 1960s (Osmundson 2001). Diversion dams in the Gunnison River have also likely affected upstream movement of Colorado pikeminnow.

At present, wild self-sustaining populations of Colorado pikeminnow are found only in the Upper Colorado River Basin. Adult (age 7+) and subadult (ages 2-6) Colorado pikeminnow are the most widely distributed of the pikeminnow life stages. These life stages occur in the mainstem Green River from its confluence with the Colorado River upstream to at least the upper reaches of Lodore Canyon (Tyus et al. 1982; Tyus 1991; McAda et al. 1994a; Bestgen and Crist 2000). Adults also occur in the Yampa River upstream to near Craig, Colorado; in the Little Snake River from its confluence with the Yampa River upstream into Wyoming; in the White River upstream to Taylor Draw Dam and Kenney Reservoir; in the lower portions of the San Rafael and Duchesne Rivers; and in the lower 143 km (89 mi) of the Price River. In the upper Colorado River subbasin, subadult and adult Colorado pikeminnow are distributed throughout the Colorado River from Palisade, Colorado, downstream to Lake Powell; in the Gunnison River from Delta, Colorado, downstream to the confluence with the Colorado River; and in the lower

[1] Habitat definitions are provided in Section 3.

2 km (1.2 mi) of the Dolores River (USFWS 2002a). Juvenile Colorado pikeminnow (ages 0 to 1) occur principally in the Green River, upper Colorado River, and Yampa River.

Distribution and abundance patterns for Colorado pikeminnow vary among life stages and seasons, and these patterns illustrate that a variety of habitat types are needed to support the species. During most of the year, adults are widely distributed, and individuals appear to occupy distinct home ranges (Tyus 1990, 1991; Irving and Modde 2000). Their distribution changes in late spring and early summer, when most mature fish migrate to spawning areas. In the Green River subbasin, well-documented spawning locations occur in the lower Yampa River in Yampa Canyon and in the lower Green River in Gray Canyon (Tyus and McAda 1984; Tyus 1985, 1990, 1991a; Irving and Modde 2000). These spawning sites are in cobble-bottomed riffle areas. The six suspected spawning areas in the upper Colorado River subbasin are all in meandering alluvial (restricted meander) reaches (McAda 2003). Adults remain in the vicinity of spawning areas for 3 to 8 weeks before returning to home ranges. Typical habitats used by adults consist of deep eddies, pools, and runs (Tyus and McAda 1984; Valdez and Masslich 1989; Tyus 1990, 1991; Osmundson et al. 1995). When such areas are available during the spring runoff period, adults and subadults use seasonally flooded habitats such as flooded bottomlands, flooded tributary mouths, flooded side canyons, and eddies (Tyus 1990, 1991; Osmundson et al. 1995).

Eggs hatch within 5 to 7 days, and larvae emerge from spawning substrate 5–7 days later. Once they emerge, larvae are swept downstream, sometimes for a considerable distance (Hamman 1981; Haynes et al. 1984; Nesler et al. 1988; Bestgen and Williams 1994; Bestgen et al. 1998). Larvae drift to relatively low-gradient river reaches where low-velocity, shallow, channel-margin habitats (e.g., backwaters) are common, and they use these habitats throughout their first year (Vanicek and Kramer 1969; Tyus and Haines 1991; Muth and Snyder 1995). Nursery habitats are primarily located in sandy, alluvial regions (USFWS 2002a).

Colorado pikeminnow nursery habitat occurs primarily in two portions of the Green River: (1) the middle Green River from Jensen, Utah, to the Duchesne River confluence and (2) the lower Green River from Green River, Utah, to the Colorado River confluence (Tyus and Haines 1991; McAda et al. 1994a,b, 1995, 1996, 1997). Historically, Echo and Island Parks also supported Colorado pikeminnow nursery habitat (Vanicek et al. 1970; Holden and Stalnaker 1975; Holden and Crist 1981). In the upper Colorado River subbasin, primary nursery habitats are located in the 103-km (64-mi) reach downstream of Moab, Utah (McAda and Ryel 1999).

Subadult Colorado pikeminnow continue to use backwaters and other low-velocity nearshore areas for several years, and then gradually shift to habitats more commonly used by adult fish (e.g., eddies, pools, and runs). Subadults appear to remain near nursery habitats in the lower portions of the Green and upper Colorado Rivers through about age 4 and then begin to move upstream as they mature and finally recruit to the adult population after about age 6 Valdez et al. 1982; Osmundson et al. 1995). In the Green River subbasin, subadult Colorado pikeminnow are most common downstream of Green River, Utah in the Green River (McAda et al. 1994a,b, 1995, 1996, 1997). Subadults are found in the White River and other tributaries (McAda et al. 1994b, 1995, 1996, 1997; Cavalli 1999), but few have been caught in the Yampa River upstream of Yampa Canyon. A few subadults were captured recently from the lower

Yampa River and the Green River in Island and Rainbow Parks (Bestgen and Crist 2000). In the upper Colorado River subbasin, subadult Colorado pikeminnow are more prevalent downstream of Westwater Canyon, while adult fish are more prevalent upstream of Westwater Canyon (Osmundson et al. 1998).

Spring peak flows are thought to provide cues to adult Colorado pikeminnow to migrate to spawning areas. These flows also affect the suitability of spawning conditions. Relatively high flows mobilize coarse sediment to build or reshape cobble bars, and they create side channels that Colorado pikeminnow sometimes use for spawning (Harvey et al. 1993).

Peak flows also transport sediment and reshape backwater nursery habitats. During high flows, the elevations of sandbars increase. As flows decrease after the peak, sandbars are eroded and the complex backwater habitats critical for early life stages of Colorado pikeminnow are formed. Some research has suggested that a single flow level might optimize backwater habitat availability (Pucherelli et al. 1990a; Tyus and Haines 1991; Tyus and Karp 1991). However, geomorphic processes are dynamic and affected by peak-flow frequency, magnitude, and duration, as well as post-peak flows (Bell et al. 1998; Rakowski and Schmidt 1999). Consequently, flows to achieve optimum backwater availability may be different each year and dependent on year-specific bar topography (Rakowski and Schmidt 1999).

2.2 HUMPBACK CHUB

The endangered humpback chub is endemic to the Upper Colorado River Basin. Historic abundance of the humpback chub is unknown, and information on historic distribution is incomplete (Tyus 1998). The species occurs primarily in relatively inaccessible canyons and was rare in most early collections (Tyus 1998). The accuracy of early assessments of distribution and abundance was hampered by uncertainties regarding the taxonomy and nomenclature of species in the genus *Gila*. The original range of the species is thought to have included most canyon reaches of the Upper Colorado River Basin. Known historic distribution of the humpback chub in the upper Colorado River subbasin includes portions of the Colorado, Green, and Yampa Rivers (USFWS 2002b).

Currently the Upper Colorado River Basin contains four populations of humpback chub: (1) Cataract Canyon (Green River to Lake Powell reach) in the Colorado River, (2) Black Rocks (Loma to Westwater Canyon reach) and Westwater Canyon in the Colorado River, (3) Desolation and Gray Canyons in the Green River, and (4) Yampa Canyon in the Yampa River (USFWS 2002b). A few humpback chubs also have been reported from the Green River in Dinosaur National Monument, primarily in Whirlpool Canyon (Holden and Stalnaker 1975; Karp and Tyus 1990) and Split Mountain Canyon (Vanicek 1967; Holden and Stalnaker 1975); from the Yampa River in Cross Mountain Canyon (Wick et al. 1981); and from the Little Snake River about 10 km (6 mi) upstream of its confluence with the Yampa River (Hawkins et al. 1996). One specimen was collected in the Gunnison River 35 km (22 mi) upstream of the Colorado River confluence, although this is not considered part of the species’ normal range (Burdick 1995).

The largest population of humpback chub in the upper basin is in Westwater Canyon and Black Rocks (Loma to Westwater Canyon reach), with an estimated combined population size of 2,900 to 6,500 adults (USFWS 2002b). The Desolation and Gray Canyon population was recently estimated at 1,500 adults, but is thought to be larger. The Yampa Canyon population is estimated at 400 to 600 adults, and the Cataract Canyon population is estimated at 500 adults (USFWS 2002b). The presence of juveniles and populations with complete size structure indicate that successful recruitment occurs in all four of the upper basin populations (USFWS 2002b).

Humpback chub complete their entire life cycle in canyons with deep water, swift currents, and rocky substrates (USFWS 2002b). Individual humpback chub show remarkable fidelity for given reaches, and little movement occurs between populations (USFWS 2002b). Fish up to about 200 mm (7.9 in.) in length (juveniles and subadults) use primarily shallow, low-velocity shoreline habitats, whereas adults use primarily offshore habitats of greater depths (Valdez and Ryel 1995; Karp and Tyus 1990; Childs et al. 1998; Chart and Lentsch 1999). Valdez et al. (1990) determined that the depth and velocities of habitats selected by humpback chub in the Yampa and Green Rivers increased as fish got larger. Juveniles are often found in areas where sand and silt are the dominant substrate, whereas boulders, sand, and bedrock substrates are used more often by older age classes (Valdez et al. 1990). In Black Rocks (Loma to Westwater Canyon reach) and Westwater Canyon, juvenile humpback chub occupy habitats similar to those of the adults (Chart and Lentsch 1999).

Humpback chub spawn from April to June over cobble bars and shoals adjacent to low-velocity shoreline eddies as flow decreases from the annual spring peak (USFWS 2002b). Emerging humpback chub larvae do not drift extensively, but instead remain in the general vicinity of spawning areas (Valdez et al. 1982; Chart and Lentsch 1999; Robinson et al. 1998). Young require low-velocity shoreline habitats, including eddies and backwaters. Humpback chubs mature in 2–3 years and may live 20–30 years (Valdez et al. 1992; Hendrickson 1993).

In Desolation and Gray Canyons, complex shorelines provide the low-velocity habitats needed by young humpback chubs. Orchard and Schmidt (2000) found that low flows (approximately 59–70 m^3/s [2,100–2,500 cfs]) result in highly complex shoreline habitats. Increasing flows reduced shoreline complexity. Chart (2000) recommended base flows of 57–113 m^3/s (2,000–4,000 cfs) during dry years in Desolation and Gray Canyons on the basis of the persistence of warm, stable backwaters and other shoreline features utilized by humpback chubs. Day et al. (2000) found that the number of shoreline eddies and backwaters was negatively correlated with flows during sampling periods but was not significantly correlated with antecedent peak-flow events.

2.3 RAZORBACK SUCKER

The endangered razorback sucker is endemic to the Colorado River Basin and was once widely distributed in warm-water reaches of larger rivers of the basin from Mexico to Wyoming (Muth et al. 2000). Historic records indicate that the lower basin supported the largest population of razorback suckers. In the Upper Colorado River Basin, although razorback suckers occurred in the Colorado, Green, and San Juan River drainages, they apparently were common only in calm, flat-water reaches of the mainstem Colorado and Green Rivers and lower portions of their major tributaries (Muth et al. 2000).

Declines in the abundance and distribution of razorback suckers were first noted in the early 1940s (Dill 1944; Wiltzius 1978). Today, the species is one of the most imperiled fishes in the Colorado River Basin and exists naturally as only a few disjunct populations or scattered individuals (Bestgen et al. 2002; Minckley et al. 1991). Although there is evidence of reproduction in the larger populations, natural survival of fish past the larval stage appears extremely low. Natural populations are primarily composed of older fish and continue to decline in abundance (Lanigan and Tyus 1989; Marsh and Minckley 1989). This lack of recruitment has been attributed mainly to the cumulative effects of habitat loss and modification caused by water and land development and predation on early life stages by nonnative fishes (Muth et al. 2000).

Razorback suckers that occupy rivers are now limited to small populations in the Upper Colorado River Basin. Although the largest riverine population is in the middle Green River (Modde et al. 1996; Tyus 1987), the most recent estimate indicates that this population has been declining with little or no recruitment and that only about 100 individuals remain (Bestgen et al. 2002). In the Colorado River upstream of Lake Powell, razorback suckers have been reported from as far upstream as DeBeque, Colorado, (river kilometers [rkm] 338 [river mile (rm) 210]). Most razorback suckers in the upper Colorado River have been captured between Loma and Palisade (Grand Valley), near the confluence of the Gunnison and Colorado Rivers. However, their abundance is very low and only 11 wild razorback suckers have been collected from the Grand Valley since 1990 (McAda 2003). Few razorback suckers have been captured downstream of the Grand Valley. Razorback suckers were considered extirpated from the Gunnison River, but recent stocking efforts have attempted to establish a population there, and some larval production was documented in 2002.

Since construction of Flaming Gorge Dam, most razorback suckers in the Upper Colorado River Basin have been collected from the mainstem Green River between rkm 282 and 552 (rm 175 and 343) and from the lower 21 km (13 mi) of the Yampa River (Muth et al. 2000). The largest concentration of razorback suckers exists in low-gradient flat-water reaches of the middle Green River between and including the lower portions of the Duchesne and Yampa Rivers. This area includes the greatest amount of floodplain habitat in the Upper Colorado River Basin (Irving and Burdick 1995). Lanigan and Tyus (1989) estimated that the middle Green River population consisted of about 1,000 adults; Modde et al. (1996) estimated the number of adults at about 500 fish; Bestgen et al (2002) estimated an adult population of only 100 fish.

Habitats used by subadult and adult razorback suckers in the Upper Colorado River Basin include deeper runs, eddies, backwaters, and flooded bottomland habitats in spring; runs and pools over submerged sandbars in summer; and low-velocity runs, pools, and eddies in winter (Tyus 1987; Osmundson and Kaeding 1989; Valdez and Masslich 1989; Tyus and Karp 1990; Modde 1997; Modde and Wick 1997; Modde and Irving 1998). Razorback sucker juveniles require nursery environments with quiet, warm, shallow water, such as flooded tributary mouths, backwaters, or inundated floodplain habitats (Smith 1959; Taba et al. 1965; Gutermuth et al. 1994; Modde 1996, 1997; Muth et al. 1998).

Razorback suckers make annual spawning runs to specific river areas (Minckley 1973). In the Green River, razorback suckers spawn between April and June over cobble, gravel, and sand substrates during spring runoff (McAda and Wydoski 1980; Tyus 1987; Tyus and Karp 1989, 1990; Muth et al. 1998). Two spawning areas have been identified in the Green River subbasin — at the mouth of the Yampa River and in the Green River upstream of Jensen, Utah, adjacent to the Escalante Ranch (recently renamed the Thunder Mountain Ranch) between rkm 486 and 504 (rm 302 and 313). A spawning area in the lower Green River near the mouth of the San Rafael River has been suggested on the basis of the presence of ripe adults and larvae (Bestgen et al. 2002; Muth et al. 2000). The location of spawning areas in the upper Colorado River subbasin is uncertain, although several razorback sucker larvae were captured from the Gunnison River upstream of the Redlands Diversion Dam in 2002, and are likely the offspring of recently stocked individuals.

Larval razorback suckers emerge from spawning substrates and are transported downstream by the current into off-channel nursery habitats with quiet, warm, shallow water (e.g., flooded tributary mouths, backwaters, and flooded bottomland habitats). The most important of these habitats are located between Split Mountain and Desolation Canyons on the Green River. Flooded bottomland habitats that provide nursery habitats are inundated during high spring-runoff flows. Some floodplain depressions are capable of retaining water after main channel flows recede, and these areas are thought to provide the most beneficial nursery habitat conditions for larval and juvenile razorback suckers. When such floodplain depressions reconnect with the main channel during subsequent high flows, razorback suckers can return to the main channel.

3 METHODS

Establishment of priorities for future geomorphology research required a process that would identify those river reaches, habitats, and underlying geomorphic processes most important in supporting endangered fish populations. Life stages vary in their dependence on specific habitat conditions and environmental variability, and any prioritization should take these differences into consideration. In addition, the population status of species varies, and priority can be given to species whose populations are in greatest peril.

We developed a linked-matrix approach to systematically and objectively identify overall priorities for research. Spreadsheets were developed to describe the relationships among various attributes and species life stages. These spreadsheets contained scores (0, 1, 2, or 3) to represent relative importance of (1) existing reach use, (2) habitat use, (3) habitat occurrence within planform types, and (4) dependencies between habitat characteristics and hydrologic and geomorphic parameters. Such a scoring system was used instead of more quantitative values (e.g., percentages or correlation coefficients) because in most cases adequate data were not consistently available for species and life stages to warrant a more quantitative approach. Scoring systems have been used in a variety of other circumstances, including (1) cumulative impact analysis of hydroelectric projects (Bain et al. 1986); (2) setting priorities for species conservation in Florida (Millsap et al. 1990); and (3) prioritizing research and monitoring needs for terrestrial mammals in national parks (Garrett and Wright 2000). The results obtained using the linked-matrix approach are presented in Section 5.

Scores also were assigned to life stages and species on the basis of sensitivity to environmental variability and population status, respectively. These scores enabled weighting of life stages and species when scores were combined to determine overall priorities. Weights were applied in a phased manner that enabled consideration of priorities at various levels, including (1) species-life stage (e.g., Colorado pikeminnow juveniles), (2) species (e.g., Colorado pikeminnow), and (3) all species combined.

Figure 2 illustrates the linkages and the mathematical operations used to calculate reach-habitat priority scores in three steps: (1) calculate reach-habitat scores for species' life stages; (2) calculate reach-habitat scores for species (all life stages combined); and (3) calculate overall reach-habitat scores (species and life stages combined).. As indicated in the figure, attribute scores were multiplied to determine priorities in most cases. For each reach and habitat combination, life-stage values were summed for a species after weighting to determine reach-habitat priorities for that species. These overall species values, in turn, were summed after applying species weighting factors to determine overall reach-habitat priorities.

Five life stages were considered for each species: larvae, juveniles, subadults, adults, and spawning. For all species, larvae were defined as individuals from emergence from the spawning substrate to settlement in nursery habitat. Juveniles were defined as individuals in their first year (and second year in the case of razorback suckers) that have completed the drifting stage and settled into nursery habitats. Subadult and adult life stage definitions vary among species. For Colorado pikeminnow, subadults are individuals between 2 and 6 years of age (< 450 mm total

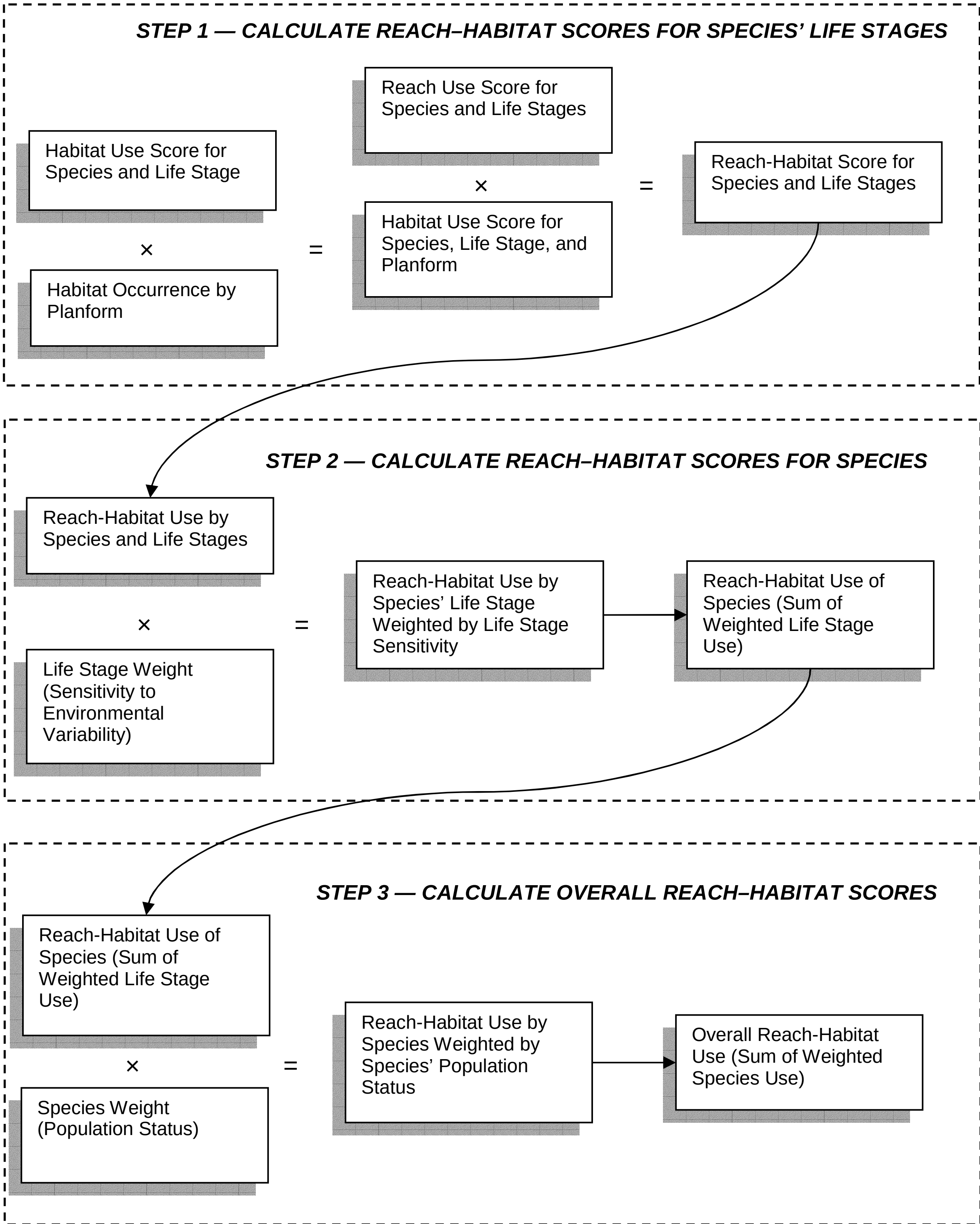

Figure 2. Linked-Matrix Approach to Determine Research Priorities for Reaches, Habitats, Life Stages, and Species. Each box represents a spreadsheet that contains scores (0, 1, 2, or 3) that reflect the relative use or importance of the attribute.

length); adults are 7 years or older (≥ 450 mm). Humpback chub subadults are defined as 2 and 3 years of age (< 200 mm); adult humpback chub are 4 or more years old and 200 mm or longer. Razorback sucker subadults are 3 years old (< 400 mm) while adults are 4 years or older and ≥ 400 mm total length. The spawning life stage of all three species includes deposited eggs, embryos in the spawning substrate, and adults on the spawning grounds.

Life Stage Definitions

Life Stage	Colorado Pikeminnow	Humpback Chub	Razorback Sucker
Larvae	Emergence to settlement in nursery habitat		
Juveniles	0–1 yr	0–1 yr	0–2 yr
Subadults	2–6 yr < 450 mm	2–3 yr < 200 mm	3 yr < 400 mm
Adults	≥ 7 yr ≥ 450 mm	≥ 4 yr ≥ 200 mm	≥ 4 yr ≥ 400 mm
Spawning	Embryos and adults in spawning habitat		

The Upper Colorado River Basin was subdivided into the Green River subbasin (Figure 3) and the upper Colorado River subbasin (Figure 4). Each major river was divided into reaches on the basis of the dominant geomorphic planform (Table 1). Three planforms were considered: (1) restricted meander, (2) fixed meander, and (3) canyon (Muth et al. 2000). These planforms describe various levels of confinement of the river channel within the surrounding geology, which in turn affects habitat characteristics relevant to endangered fishes. Restricted meanders occur in broad alluvial terraces that are bounded by relatively more resistant geology. Valleys in which restricted meanders occur are relatively wide, and only the outside bends are in contact with bedrock. Fixed meanders are confined by resistant geology on both outside and inside bends of the main channel and result from symmetrical incision associated with rapid down-cutting through the geologic formation. Canyons consist of relatively straight sections of river with resistant geology on both sides of the river.

Channel Planform Definitions

Channel planform – The configuration of a stream as seen from above. Three channel planforms, defined below, are found in the Upper Colorado River Basin.

Restricted meander – Sinuous portion of river that flows through broad alluvial terraces bounded by relatively more resistant geology. Only the outside bends are in contact with bedrock.

Fixed meander – Sinuous portion of river that is confined by resistant geology on both outside and inside bends.

Canyon – Relatively straight sections of the river confined on both sides by resistant geology.

Each river reach was assigned a score for each species and life stage that represented the relative use of that particular reach by that species and life stage under existing conditions. Information on distributions from the past decade was used to determine existing conditions for the Colorado pikeminnow and humpback chub; for the razorback sucker, information from the past two decades were used because data for this species is more limited. Scores of 0, 1, 2, or 3 were used to indicate no, little, moderate, or high use, respectively. Reach-use scores for species within each subbasin were developed separately and were based on overall occurrence of the

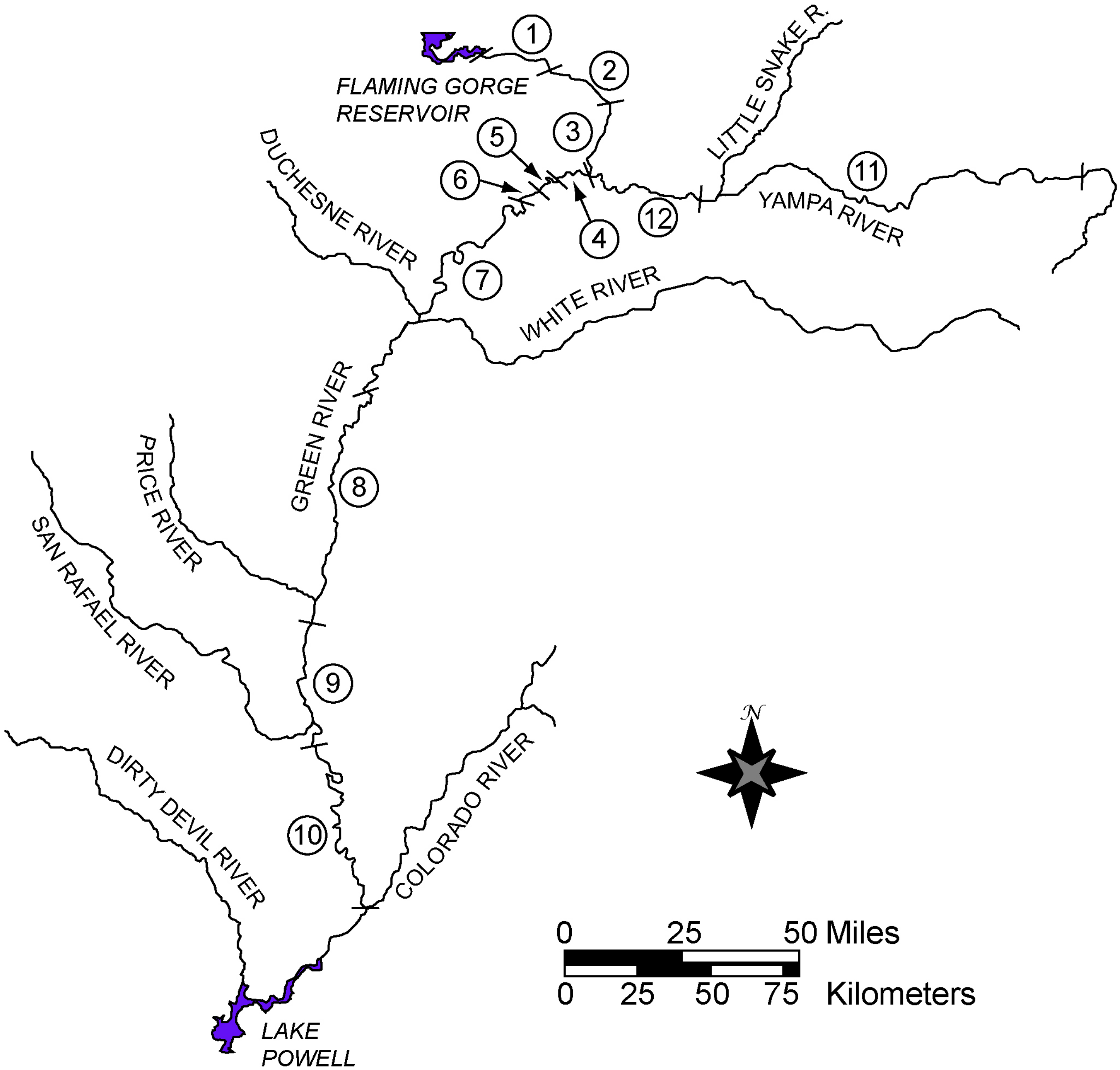

Figure 3. Green River Reaches and Tributaries. (Numbers correspond to reach names given in Table 1.)

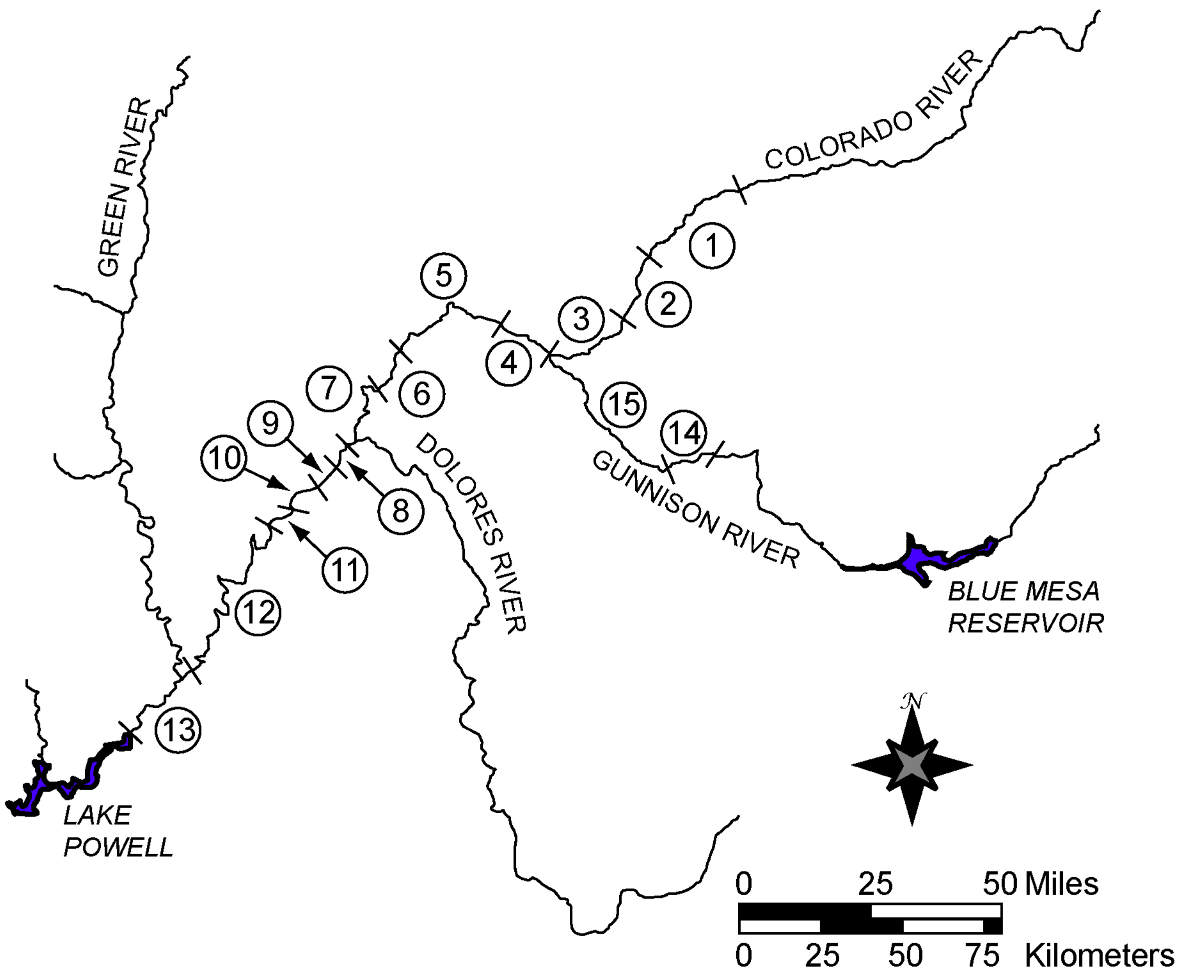

Figure 4. Upper Colorado River Reaches and Tributaries. (Numbers correspond to reach names given in Table 1.)

Table 1. Location and Dominant Planforms of River Reaches of the Upper Colorado River Basin

	River Reach[a]	River Km[b]	River Mi[b]	Dominant Planform
I. Green River Subbasin				
Green River Mainstem				
1	Flaming Gorge Dam to Browns Park	637–660	396–410	Canyon
2	Browns Park	583–637	362–396	Restricted meander
3	Lodore Canyon	551–583	342–362	Canyon
4	Yampa River to Island Park	538–551	334–342	Canyon
5	Island and Rainbow Parks	526–538	326–334	Restricted meander
6	Split Mountain Canyon	514–526	319–326	Canyon
7	Split Mountain Canyon to Desolation Canyon	348–514	216–319	Restricted meander
8	Desolation and Gray Canyons	212–348	132–216	Canyon
9	Gray Canyon to Labyrinth Canyon	148–212	92–132	Restricted meander
10	Labyrinth and Stillwater Canyons	0–148	0–92	Fixed meander
Green River Tributaries				
11	Yampa River–Above Yampa Canyon	72–208	45–129	Restricted meander
12	Yampa River–Yampa Canyon	0–72	0–45	Canyon
	Little Snake River	–	–	Restricted meander
	Duchesne River	–	–	Restricted meander
	White River	–	–	Restricted meander
	Price River	–	–	Fixed meander
	San Rafael River	–	–	Restricted meander
II. Upper Colorado River Subbasin				
Colorado River Mainstem				
1	Rulison to DeBeque Canyon	328–373	204–232	Restricted meander
2	DeBeque Canyon to Palisade	298–328	185–204	Fixed meander
3	Palisade to Gunnison River	275–298	171–185	Restricted meander
4	Gunnison River to Loma	248–275	154–171	Restricted meander
5	Loma to Westwater Canyon	201–248	125–154	Fixed meander[c]
6	Westwater Canyon	182–201	113–125	Canyon
7	Cottonwood Wash to Dewey Bridge	151–182	94–113	Restricted meander
8	Dewey Bridge to Hittle Bottom	142–151	88–94	Fixed meander
9	Hittle Bottom to White Rapid	126–142	78–88	Restricted meander
10	White Rapid to Jackass Canyon	113–126	70–78	Fixed meander
11	Jackass Canyon to Moab Bridge	103–113	64–70	Fixed meander
12	Moab Bridge to Green River	0-103	0-64	Fixed meander
13	Green River to Lake Powell	-23–0	-14–0	Canyon
Colorado River Tributaries				
14	Gunnison River–Hartland Dam to Roubideau Cr.	94–107	58–66	Restricted meander
15	Gunnison River–Roubideau Cr. to Colorado River	0–94	0–58	Fixed meander
	Dolores River	–	–	Fixed meander

[a] Reach numbers refer to locations of reaches shown in Figures 3 (Green River subbasin) and 4 (upper Colorado River subbasin).

[b] River kilometer and river mile represent distance from river mouth as follows: Green River, distance upstream of Colorado River; Yampa River, distance upstream of Green River; Colorado River, distance upstream of Green River; Gunnison River, distance upstream of Colorado River. "–" indicates entire tributary considered.

[c] The Loma to Westwater Canyon reach includes Black Rocks, a 1.5-mi (2.4-km) canyon.

species within the subbasin; thus, each reach and tributary within the Green River subbasin was scored relative to a species' population within the Green River subbasin, and each reach and tributary within the upper Colorado River subbasin was scored relative to a species' population within the upper Colorado River subbasin. This approach was used because of the differences in population sizes (and apparently carrying capacities) between the two subbasins (see Section 2).

Habitat use was also scored for species and life stages. Habitat types considered included pools, runs, riffles/rapids, connected backwaters, side channels, eddies, flooded tributary mouths, and flooded bottomlands. These habitats represent main-channel, channel-margin, and off-channel habitats.

The distribution, characteristics, and importance of habitat types to species and life stages vary among planforms, and, thus, scoring of habitats was planform-specific. As an example, few connected backwaters occur in canyons, but these habitats are abundant in restricted meanders. These differences were reflected in scores of 1 and 3 for canyons and restricted meanders, respectively.

Habitat use can vary among planform types because planform affects habitat characteristics important to the fishes. Habitat use scores for each reach were based on the dominant planform of that reach. For example, the use of connected backwaters by juvenile pikeminnow is low in canyons but high in restricted meanders and is, therefore, scored 1 and 3 in canyons and restricted meanders, respectively. As shown in Figure 2, scores for habitat occurrence in a planform and habitat use within a planform were multiplied to determine habitat scores for species, life stage, and planform combinations. These values were then multiplied by reach use values for all reaches of that planform type.

Habitat Definitions (adapted from Armantrout 1998)

I. <u>Main-Channel Habitats</u>

Pool – main-channel habitat with little velocity that is normally deeper and wider than habitats immediately above and below it

Run **–** area of swiftly flowing water, little or no surface waves, turbulence or flow obstruction

Riffle/Rapid **–** shallow habitats of moderate to high gradient, rough and broken surface, and coarse substrate

II. <u>Channel-Margin Habitats</u>

Connected backwater **–** side channel in which the inlet becomes blocked with sediment at lower flows but the outlet remains connected with the active main channel

Side channel **–** elongated flowing water extension off the main channel

Eddy **–** a pool on the margin or off the main channel in a stream that is formed and maintained by a circular current forming where water flows past an obstruction or on an inside bend

Flooded tributary mouth **–** area of still water at the confluence of a tributary and mainstem river that is inundated by mainstem river and tributary flow

III. <u>Off-Channel Habitat</u>

Flooded Bottomland **–** area within the floodplain of a river that has standing water

The process (step 1 in Figure 2) can be illustrated by showing calculations for a specific species, life stage, reach, and habitat combination, in this case, Colorado pikeminnow juveniles in connected backwaters of the Split Mountain Canyon to Desolation Canyon reach of the Green River, which is a restricted meander:

1. Juvenile use of Split Mountain Canyon to Desolation Canyon, (3)
2. Occurrence of connected backwaters in restricted meanders, (3)
3. Use of connected backwaters in restricted meanders, (3)
4. Calculated score for juveniles in reach-habitat combination: 3 × 3 × 3 = 27

Through this process, scores were obtained for all species, life-stage, reach, and habitat combinations.[2] The values for these combinations were then compared to determine reach–habitat priorities for species life stages (Figure 2). Composite scores ranged from 0 to 27.

Life-Stage Weights Based on Sensitivity to Environmental Variability

Species	Larvae	Juvenile	Subadult	Adult
Colorado pikeminnow	1	3	1	1
Razorback sucker	1	3	1	1
Humpback chub	1	2	1	1

1 = relatively insensitive
2 = moderately sensitive
3 = very sensitive

To determine the overall score for a species (i.e., to consider all life stages together) for a particular reach-habitat combination, one could simply add scores for that combination. Prior to adding life-stage values together, however, we applied a weighting factor to life stage scores to reflect differences in the sensitivity of life stages to environmental variability. Increasing sensitivity to environmental change can result in impediments to species recovery. Thus, the juveniles of most species are most sensitive, and survival of this life stage is a critical limiting factor for many populations. Reach–habitat scores for each species' life stage were multiplied by life-stage weighting factors, and then these values were summed for each reach–habitat combination to determine priorities for the species.

The following example illustrates the process for Colorado pikeminnow use of connected backwaters in the Split Mountain Canyon to Desolation Canyon reach of the Green River (step 2 in Figure 2):

1. Reach-habitat score for larvae (27) × life stage weight (1) = 27
2. Reach-habitat score for juveniles (27) × life stage weight (3) = 81
3. Reach-habitat score for subadults (18) × life stage weight (1) = 18
4. Reach-habitat score for adults (18) × life stage weight (1) = 18
5. Combined reach-habitat score for Colorado pikeminnow = 27 + 81 + 18 + 18 = 144

[2] The spawning life stage was not included in these and other calculations. Spawning in many respects is not equivalent to other life stages. Spawning habitat is typically a complex of habitats that may only be available for a brief period of time and cannot be used by some other life stages (e.g., juveniles). Our scoring system combines across life stages, and calculations would be complicated by this disparity. In addition, provision of spawning habitats is essential for the survival of each species. For these reasons, spawning habitats for each species were prioritized based solely on the importance of different river reaches for spawning.

Through this process, scores were obtained for all species, reach, and habitat combinations. The values for these combinations were then compared to determine reach–habitat priorities for each species (Figure 2). Reach-habitat scores for species could range from 0 to 162.

Species Weights Based on Population Status

Species	Green River Subbasin	Colorado River Subbasin
Colorado pikeminnow	1	2
Humpback chub	2	1
Razorback sucker	3	3

1 = relatively stable, large population
2 = moderately stable, intermediate-sized population
3 = unstable, small population

Before adding species values together to obtain total scores for reach-habitat combinations, we applied a species weighting factor that was intended to reflect differences in the population status of species. Under this scheme, species whose populations are considered relatively less secure were given higher weight than those whose populations are more secure. Species weighting factors were not the same for the Green River subbasin and upper Colorado River subbasin to reflect differences in population status between the two river systems. Reach–habitat scores for each species were multiplied by species weighting factors, and then these values were summed for each reach–habitat combination to determine overall (non-species-specific) priorities. The following example illustrates the process of computing an overall score for all species in connected backwaters in the Split Mountain Canyon to Desolation Canyon reach of the Green River (step 3 in Figure 2):

1. Reach-habitat score for Colorado pikeminnow (144) × species weight (1) = 144
2. Reach-habitat score for humpback chub (0) × species weight (2) = 0
3. Reach-habitat score for razorback sucker (108) × species weight (3) = 324
4. Combined reach-habitat score for all species = 144 + 0 + 324 = 468

Through this process, scores were obtained for all reach and habitat combinations. The values for these combinations were then compared to determine overall reach-habitat priorities (Figure 2). Overall reach-habitat scores could range from 0 to 972.

Base flow – Flows that occur after the annual snow-melt runoff period, usually from early summer to the following spring. Characteristics used to describe base flows include:

- *Magnitude* – Overall flow level during the base-flow period
- *Duration* – Length of time between the onset of the base-flow period in early summer and the beginning of snow-melt runoff in the following spring
- *Timing* – Date of the onset of the base-flow period
- *Variability* – Variation in base-flow magnitude among years (inter-annual), within years (intra-annual), and within days

The process described above was used to identify priorities for reaches and habitats, but it did not prioritize the geomorphic and flow parameters that should be studied. In order to prioritize those parameters, the important characteristics of each habitat type were identified (Table 2). Spawning bar complexes were considered in this evaluation of geomorphic parameters and habitat characteristics, but as discussed elsewhere, were not included in the identification of reach-habitat priorities. Most fish spawn over clean cobble and gravel bars, which can be considered

Table 2. Characteristics of Habitat Types Important to Endangered Fishes

Habitat Type	Important Habitat Characteristics
Pools	Dimension, amount of habitat in reach, connectedness to other habitats, intra-annual stability, bed composition
Runs	Dimension, amount of habitat in reach, shoreline complexity, intra-annual stability, bed composition
Riffles/rapids	Dimension, amount of habitat in reach, intra-annual stability, bed composition
Connected backwaters	Dimension, amount of habitat in reach, initial timing of availability, inter-annual availability, intra-annual stability, within-day stability
Side channels	Dimension, amount of habitat in reach, initial timing of availability, inter-annual availability, intra-annual stability
Eddies	Dimension, amount of habitat in reach, shoreline complexity, inter-annual stability, intra-annual stability, bed composition
Flooded tributary mouths	Dimension, amount of habitat in reach, initial timing of availability, inter-annual availability, intra-annual stability
Flooded bottomlands	Dimension, amount of habitat in reach, initial timing of availability, inter-annual availability, intra-annual stability, connection to channel
Spawning bar complexes	Dimension, amount of habitat in reach, initial timing of availability, inter-annual availability, intra-annual stability, velocity, bed composition

riffle/rapid habitats (see Section 2), but these areas are typically collocated with other habitats (e.g., pools, eddies, runs, and side channels) that are used by spawning fish for staging, feeding, and resting. It is the collocation of these habitats with suitable riffle/rapid habitat that appears to attract spawning fish.

Peak flow – Flows that occur during the annual snow-melt runoff, usually from mid to late spring. Characteristics used to describe peak flows include:

- *Magnitude* – Overall flow level during spring runoff or the highest annual daily flow
- *Duration* – Length of the spring-runoff period or the length of time above any threshold flow (e.g., bankfull flow) during spring runoff
- *Frequency* – Percentage of years annual peak flows reach or exceed some threshold flow (e.g., bankfull flow)
- *Timing* – Date of the onset of spring runoff, date some threshold flow is achieved, or date of the highest annual daily flow
- *Variability* – Variation in peak-flow magnitude among years (inter-annual), or variation in flow magnitude during runoff period (intra-annual)

Hydrologic and geomorphic parameters that affect each habitat characteristic were scored according to the strength of the relationship. Scores of 0, 1, 2, or 3 were used to represent no, weak, moderate, or strong dependence, respectively, of the habitat characteristic on that parameter. Parameters considered in the evaluation included channel morphology, hydraulics, sediment particle size, sediment availability, base-flow characteristics (including magnitude, duration, timing, and variability), and peak-flow characteristics (including magnitude, duration, frequency, timing, and variability). The nature of the relationship of each of these parameters to important habitat characteristics is presented in Table 3. Scores applied to dependencies are presented in Section 6.1.

Table 3. Hydrologic and Geomorphic Parameters and Their Hypothesized Relationships to the Characteristics of Endangered Fish Habitats

Parameter	Relationship to Habitat Characteristics
Channel morphology	Affects habitat dimension, amount and types of habitat in reach, sediment transport rates
Hydraulics	Affects movement of water and sediment through system and therefore habitat dimension, amount and types of habitat in reach, and sediment erosion and deposition patterns
Sediment particle size	Affects erosion and aggradation rates, bed composition
Sediment availability	Affects erosion and aggradation rates, bed composition
Base-flow magnitude	Affects fine sediment transport rates, bed composition, dimension of in-channel habitats and groundwater-connected flooded bottomland habitats, types of in-channel habitat in reach, amount of habitat in reach, vegetation encroachment, velocity in spawning habitats, shoreline complexity
Base-flow-duration	Affects fine sediment transport rates, bed composition, availability of in-channel habitats and groundwater-connected flooded bottomland habitats
Base-flow timing	Affects timing of in-channel habitat availability
Base-flow variability	Affects inter-annual availability of habitats, intra-annual habitat stability, and within-day habitat stability
Peak-flow magnitude	Affects sediment-transport rates, erosion and aggradation rates, habitat dimension, bed composition, inundation and connection of flooded bottomland habitats, vegetation encroachment, changes in channel width
Peak-flow duration	Affects sediment transport rates, erosion and aggradation rates, habitat dimension, bed composition, duration of inundation and connection of flooded bottomland habitats, vegetation encroachment, changes in channel width
Peak-flow frequency	Affects sediment transport rates, net erosion and aggradation rates, habitat dimension, bed composition, rates of channel-width change, rates of vegetation encroachment, frequency of connection to flooded bottomlands
Peak-flow timing	Affects timing of availability of flooded bottomland habitats; timing relative to sediment inputs affects sediment transport rates, erosion and aggradation rates, habitat dimension, vegetation encroachment, changes in channel width
Peak flow variability	Affects inter-annual availability and intra-annual stability of flooded bottomland habitats, vegetation encroachment, changes in channel width, erosion and aggradation rates, habitat dimension

Two workshops were held (December 11 and 12, 2002 and February 3 and 4, 2003) to provide a forum in which researchers could discuss findings and provide input. Representatives from the USFWS, National Park Service, Bureau of Reclamation, Western Area Power Administration, USGS, UDWR, Colorado Division of Wildlife, Wyoming Game and Fish Department, Nature Conservancy, Colorado River Water Conservation District, Colorado River Energy Distributors Association, and several universities and private consulting firms participated in the workshops (see Appendix A for a list of workshop participants). During these workshops, participants discussed the attributes to consider in determining research priorities and their definitions. In addition, scores were assigned for existing levels of reach and habitat use.

The approach used at the workshops was similar to a Delphi approach (Linstone and Turoff 2002), in which input from a group of experts was used to reach consensus on assigned attribute scores.

Once scores were obtained for species and life stages on the basis of existing levels of reach use, consideration was given to potential use of reaches assuming improvements in conditions in response to site-specific management actions designed to conserve the species (e.g., implementation of flow recommendations, planned removal of existing barriers to passage, control of non-native species, and successful establishment of populations through augmentation). Consideration of potential reach use was considered especially important for razorback sucker in the upper Colorado River subbasin, because existing levels of use are so low and so few larvae and juveniles exist in the system. Potential reach use scores were developed after the workshops based on input from researchers from the USFWS and UDWR. Existing reach-use values were replaced with these scores and priority scores recalculated following the same procedures shown in Figure 2.

Although the approach used here prioritizes individual habitats, reaches, and rivers for study in the Upper Colorado River Basin, strong linkages exist among these and they cannot be viewed in isolation. To understand the geomorphic processes important in shaping an individual habitat in a particular reach and river will require a determination of how the habitat functions in context with the entire fluvial system. Similarly, life stages of species cannot be viewed in isolation, and all are obviously necessary to the species’ survival. Our approach identifies the reaches and habitats that have the highest priority information needs. To understand these individual reaches and habitats, we need to understand critical relationships to other system components.

4 PREVIOUS RESEARCH IN THE UPPER COLORADO RIVER BASIN

The Recovery Program has funded and conducted considerable research to better understand the linkages between geomorphic processes and endangered fish habitats. In addition, a number of projects and reports have focused on synthesizing existing information about endangered fish biology and habitat needs. This section identifies and summarizes past work and reports that have examined geomorphic processes and habitats for endangered fishes in the Upper Colorado River Basin. The purpose is to define the state of knowledge for important topic areas by considering the extent to which various geomorphic processes and habitat needs have been investigated and by identifying which reaches of the river have been considered in those investigations. References are organized according to river reach, and the attributes studied are identified for each in Tables 4, 5, and 6.

4.1 GREEN RIVER AND TRIBUTARIES

Table 4 lists geomorphic and habitat studies conducted in the mainstem Green River, and Table 5 presents similar information for Green River tributaries. Past research results and information pertaining to the Green River and its tributaries have been synthesized in flow recommendations for the Green River subbasin (Muth et al. 2000), Yampa River (Modde et al. 1999), Duchesne River (Modde et al. 2002), and White River (Lentsch et al. 2000).

Flow hydraulics, sediment supply, and sediment transport information is basic to understanding many of the geomorphic processes that create or maintain important habitats for endangered fishes. Information on these topics has been collected for most reaches of the Green River, as well as for most Green River tributaries. In the Green River, the most comprehensive studies have been conducted by Andrews (1986), Lyons et al. (1992), FLO Engineering, Inc. (1997a), and Grams and Schmidt (1999). Similar studies in Green River tributaries have been conducted in the Yampa River (Andrews 1980; Elliot et al. 1984), Little Snake River (Andrews 1980), and White River (Tobin 1993).

Nursery habitats are critically important in maintaining growth and survival of juveniles and supporting successful recruitment to the adult population. Furthermore, nursery habitats of both Colorado pikeminnow and razorback suckers are concentrated in the Split Mountain Canyon to Desolation Canyon reach of the Green River. As a consequence, many studies have examined the availability and characteristics of these habitats, as well as related geomorphic processes in this particular reach (Table 4).

The availability of flooded bottomland habitats for razorback suckers has been the focus of many studies in the Split Mountain Canyon to Desolation Canyon reach (e.g., Cooper and Severn 1994a; Irving and Burdick 1995; Modde 1996, 1997; Bell et al. 1998; Bell undated; Birchell et al. 2001). Relatively fewer studies of flooded bottomland habitat have been conducted in other reaches of the Green River where such habitat is less common (Schmidt 1994; Irving and Burdick 1995; Cluer and Hammack 1999).

Table 4. Geomorphic and Habitat Studies Conducted in the Green River

Reach/Citation[a]	Attributes Studied
Entire River	
Muth et al. (2000)	Flow recommendations
Schmidt (1994)	Peak-flow magnitude, historical trends, sediment, channel narrowing, floodplain inundation
Schmidt (1996)	Colorado pikeminnow, larvae, juveniles, backwater habitat, habitat formation, larval drift, shoreline complexity
Flaming Gorge Dam to Browns Park (Reach 1)	
Grams (1999)	Sediment supply
Yin et al. (1995)	Flow hydraulics
Browns Park (Reach 2)	
Andrews (1986)	Sediment transport, channel narrowing, peak-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Merritt and Cooper (2000)	Channel morphology, vegetation encroachment, sediment
Williams et al. (1995)	Sediment transport
Lodore Canyon (Reach 3)	
Grams and Schmidt (1999)	Channel morphology, riffle/rapid habitat, eddy habitat, sediment transport
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Martin et al. (1998)	Sediment transport, channel narrowing, vegetation encroachment, peak-flow magnitude
Yin et al. (1995)	Flow hydraulics
Yampa River to Island Park (Reach 4)	
Grams and Schmidt (1999)	Channel morphology, riffle/rapid habitat, eddy habitat, sediment transport
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lyons et al. (1992)	Sediment transport, channel narrowing
Valdez and Masslich (1989)	Colorado pikeminnow, razorback sucker, habitat use
Island and Rainbow Parks (Reach 5)	
Cluer and Hammack (1999)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Grams and Schmidt (1999)	Channel morphology, riffle/rapid habitat, eddy habitat, sediment transport
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lyons et al. (1992)	Sediment transport, channel narrowing
Pucherelli et al. (1990a)	Backwater habitat, habitat availability, base-flow magnitude
Valdez and Masslich (1989)	Colorado pikeminnow, razorback sucker, habitat use

Table 4 (Cont.)

Reach/Citation[a]	Attributes Studied
Split Mountain Canyon (Reach 6)	
Grams and Schmidt (1999)	Channel morphology, riffle/rapid habitat, eddy habitat, sediment transport
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lyons et al. (1992)	Sediment transport, channel narrowing
Split Mountain Canyon to Desolation Canyon (Reach 7)	
Andrews (1986)	Sediment transport, channel narrowing, peak-flow magnitude
Bell et al. (1998)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Bell (undated)	Flooded bottomland habitat, backwater habitat, habitat availability, peak-flow magnitude, base-flow magnitude
Birchell et al. (2001)	Flooded bottomland habitat, razorback sucker, Colorado pikeminnow, adults, larvae, habitat availability, peak-flow magnitude, restoration
Cooper and Severn (1994a)	Flooded bottomland habitat, habitat availability, peak-flow magnitude, water quality, restoration
Day et al. (1999)	Colorado pikeminnow, young-of-the-year, backwater use, peak-flow magnitude, peak-flow frequency, base-flow magnitude
FLO Engineering (1996)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
FLO Engineering (1997a)	Flow hydraulics
FLO Engineering (1997b)	Flooded bottomland habitat, habitat availability, peak-flow magnitude, restoration
Guensch and Schmidt (1996)	Backwater habitat, habitat formation, peak-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lyons et al. (1992)	Sediment transport, channel narrowing
Modde (1996, 1997)	Razorback sucker, juveniles, flooded bottomland habitat, habitat use, habitat availability, peak-flow magnitude
Modde and Irving (1998)	Razorback sucker, adults, spawning habitat, habitat use
Modde and Wick (1997)	Razorback sucker, larvae, juveniles, adults, flooded bottomland habitat, spawning habitat, habitat use, habitat availability, peak-flow magnitude
O’Brien (1998)	Sediment transport
Pucherelli et al. (1990a)	Backwater habitat, habitat availability, base-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Rakowski and Schmidt (1999)	Colorado pikeminnow, juveniles, backwater habitat, habitat formation, habitat availability, peak-flow magnitude, base-flow magnitude
Trammel and Chart (1999a)	Colorado pikeminnow, young-of-the-year, habitat use, habitat availability, habitat formation, peak-flow magnitude, base-flow magnitude
Valdez and Masslich (1989)	Colorado pikeminnow, razorback sucker, habitat use
Wick (1997)	Razorback sucker, spawning, spawning habitat, habitat formation, sediment, peak-flow magnitude, peak-flow timing
Yin et al. (1995)	Flow hydraulics

Table 4 (Cont.)

Reach/Citation[a]	Attributes Studied
Desolation and Gray Canyons (Reach 8)	
Chart and Lentsch (2000)	Colorado pikeminnow, humpback chub, spawning, adults, juveniles, peak-flow magnitude
Day et al. (2000)	Colorado pikeminnow, humpback chub, young-of-the-year, habitat use, backwater habitat, eddy habitat, peak-flow magnitude, peak-flow frequency, base-flow magnitude
FLO Engineering (1997a)	Flow hydraulics
Harvey and Mussetter (1994)	Colorado pikeminnow, spawning habitat, habitat formation, hydraulic modeling, peak-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Orchard and Schmidt (2000)	Humpback chub, eddy habitat, habitat availability, channel narrowing, vegetation encroachment
Schmidt et al. (1996)	Eddy habitat, habitat availability, peak-flow magnitude, base-flow magnitude, vegetation encroachment
Gray Canyon to Labyrinth Canyon (Reach 9)	
Allred and Schmidt (1999)	Channel narrowing, vegetation encroachment, peak-flow magnitude
Andrews (1986)	Sediment transport, channel narrowing, peak-flow magnitude
Chart et al. (1999)	Colorado pikeminnow, spawning, larvae, razorback sucker, flooded tributary mouth habitat
FLO Engineering (1997a)	Flow hydraulics
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lyons et al. (1992)	Sediment transport, channel narrowing
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Labyrinth and Stillwater Canyons (Reach 10)	
Chart et al. (1999)	Colorado pikeminnow, razorback sucker, spawning, larvae, flooded tributary mouth habitat
Cluer and Hammack (1999)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
FLO Engineering (1996)	Side-canyon backwater habitat, habitat availability, peak-flow magnitude
FLO Engineering (1997a)	Flow hydraulics
Guensch and Schmidt (1996)	Backwater habitat, habitat formation, peak-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Pucherelli et al. (1990a)	Backwater habitat, habitat availability, base-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Trammel and Chart (1999a)	Colorado pikeminnow, young-of-the-year, habitat use, habitat availability, habitat formation, peak-flow magnitude, base-flow magnitude

[a] Reach numbers correspond to locations shown in Figure 3. Dominant planform in reaches are given in Table 1.

Table 5. Geomorphic and Habitat Studies Conducted in Green River Tributaries

Reach/Citation[a]	Attributes Studied
Yampa River–Above Yampa Canyon (Reach 11)	
Andrews (1980)	Sediment transport, peak-flow magnitude, bankfull discharge
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Merritt and Cooper (2000)	Channel morphology, vegetation encroachment, sediment
Modde et al. (1999)	Hydrology, channel morphology, Colorado pikeminnow, humpback chub, habitat use, habitat availability, base-flow magnitude, flow recommendations
Wick et al. (1983)	Colorado pikeminnow, adults, habitat use
Yampa River–Yampa Canyon (Reach 12)	
Andrews (1980)	Sediment transport, peak-flow magnitude, bankfull discharge
Harvey et al. (1993)	Colorado pikeminnow, spawning habitat formation, hydraulic modeling, peak-flow magnitude
Elliot et al. (1984)	Sediment transport
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Karp and Tyus (1990)	Humpback chub, adults, spawning, habitat use
Miller and Rees (1997)	Colorado pikeminnow, adults, habitat use, base-flow magnitude
Modde et al. (1999)	Hydrology, channel morphology, Colorado pikeminnow, humpback chub, habitat use, habitat availability, base-flow magnitude, flow recommendations
Tyus and Karp (1989)	Colorado pikeminnow, humpback chub, adults, spawning, habitat use
Tyus and McAda (1984)	Colorado pikeminnow, adults, habitat use
Wick and Hawkins (1989)	Colorado pikeminnow, adults, habitat use
Wick et al. (1983)	Colorado pikeminnow, adults, habitat use
Little Snake River	
Andrews (1980)	Sediment transport
Hawkins and O'Brien (2001)	Sediment, channel morphology, hydrology
Duchesne River	
Modde et al. (2002)	Colorado pikeminnow, razorback sucker, adults, juveniles, habitat use, habitat availability, peak-flow magnitude, base-flow magnitude, flow recommendations
White River	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Irving and Modde (2000)	Colorado pikeminnow, adults, habitat use
Lentsch et al. (2000)	Hydrology, sediment, Colorado pikeminnow, adults, subadults, channel morphology, habitat availability, water quality, flow recommendations
Tobin (1993)	Sediment transport
Tyus and McAda (1984)	Colorado pikeminnow, adults, habitat use

Table 5 (Cont.)

Reach/Citation[a]	Attributes Studied
Price River	
Cavalli (1999)	Colorado pikeminnow, adults, distribution
San Rafael River	
Chart et al. (1999)	Colorado pikeminnow, razorback sucker, spawning, larvae, flooded tributary mouth habitat

[a] Reach numbers correspond to locations shown in Figure 3. Dominant planform in reaches are given in Table 1.

Similarly, research on habitat characteristics and availability of connected backwaters, which are important nursery habitats for Colorado pikeminnow, has focused on the Split Mountain Canyon to Desolation Canyon reach of the Green River (e.g., Bell undated; Day et al. 1999; Guensch and Schmidt 1996; Pucherelli et al. 1990a,b; Rakowski and Schmidt 1999; Trammell and Chart 1999a). Fewer studies have been conducted in other reaches of the Green River where fewer backwaters are found (e.g., Pucherelli et al. 1990a,b; Guensch and Schmidt 1996; Day et al. 2000).

Spawning habitats have been studied in several areas of the Green River and its tributaries. Characteristics of razorback sucker spawning sites in the Green River and the effects of flow regimes on spawning bar characteristics and fish use of spawning areas have been studied by Modde and Wick (1997), Wick (1997), and Modde and Irving (1998). Harvey et al. (1993) described hydraulic conditions and sediment transport and deposition on the Colorado pikeminnow spawning bar in Yampa Canyon. Effects of flows on conditions at the Colorado pikeminnow spawning bar in Gray Canyon of the Green River were studied by Harvey and Mussetter (1994).

Studies on habitats used by humpback chub in the Green River have focused on Desolation and Gray Canyons, where most humpback chub are found. These studies have primarily examined habitats used by juveniles, subadults, and adults (Chart and Lentsch 2000; Day et al. 2000; Orchard and Schmidt 2000). Use and characteristics of habitats for humpback chub have also been studied in Yampa Canyon (e.g., Tyus and Karp 1989; Karp and Tyus 1990; Modde et al. 1999).

4.2 UPPER COLORADO RIVER AND TRIBUTARIES

Geomorphic and habitat studies conducted in the upper Colorado River and its tributaries are presented in Table 6. As for the Green River subbasin, a considerable amount of information is available for the subbasin, and at least some studies have been conducted in all reaches. Much of this information has been summarized and incorporated into flow recommendation reports for the mainstem upper Colorado River both upstream (Kaeding and Osmundson 1989; Osmundson et al. 1995; Osmundson 2001) and downstream (McAda 2003) of the Gunnison River confluence and for the Gunnison River itself (McAda 2003).

Table 6. Geomorphic and Habitat Studies Conducted in the Upper Colorado River and Tributaries

Reach/Citation	Attributes Studied
Rulison to DeBeque Canyon (Reach 1)	
Carter et al. (1985)	Habitat availability, flooded bottomland habitat, in-channel habitats, peak-flow magnitude, base-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
Osmundson (2001)	Colorado pikeminnow, razorback sucker, peak-flow magnitude, base-flow magnitude, flow recommendations
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport, channel narrowing, side channel habitat, backwater habitat, peak-flow magnitude
DeBeque Canyon to Palisade (Reach 2)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
Osmundson (2001)	Colorado pikeminnow, razorback sucker, peak-flow magnitude, base-flow magnitude, flow recommendations
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Pitlick et al. (1999)	Channel morphology, sediment transport, habitat formation, channel narrowing, peak-flow magnitude, peak-flow duration
Palisade to Gunnison River (Reach 3)	
Anderson (1999)	Colorado pikeminnow, spawning, larvae, peak-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Hann and Rose (1989)	Colorado pikeminnow, adults, habitat availability, base-flow magnitude
Kaeding and Osmundson (1989)	Colorado pikeminnow, razorback sucker, adults, summer flow recommendations
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
Miller et al. (2002)	Sediment transport, food base, riffle/rapid habitat, run habitat, bed characteristics, peak-flow magnitude, base-flow magnitude, hydraulic modeling
Osmundson (2000)	Colorado pikeminnow, razorback sucker, adults, spawning, flooded bottomland habitat, food base
Osmundson and Kaeding (1991)	Colorado pikeminnow, razorback sucker, adults, habitat availability, habitat use, base-flow magnitude, winter flow recommendations
Osmundson and Scheer (1998)	Sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, peak-flow magnitude

Table 6 (Cont.)

Reach/Citation	Attributes Studied
Palisade to Gunnison River (Cont.)	
Osmundson et al. (1995)	Colorado pikeminnow, razorback sucker, adults, habitat availability, habitat use, peak-flow magnitude, base-flow magnitude, flow recommendations
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Pitlick et al. (1999)	Channel morphology, sediment transport, habitat formation, channel narrowing, peak-flow magnitude, peak-flow duration
Pitlick and Van Steeter (1998)	Peak-flow magnitude, sediment transport, channel narrowing, side channel habitat, backwater habitat, habitat maintenance
Van Steeter and Pitlick (1998)	Peak-flow magnitude, sediment transport, channel narrowing, side channel habitat, backwater habitat
Gunnison River to Loma (Reach 4)	
Anderson (1999)	Colorado pikeminnow, spawning, larvae, peak-flow magnitude
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude
Osmundson and Scheer (1998)	Sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, peak-flow magnitude
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Pitlick and Van Steeter (1998)	Peak-flow magnitude, sediment transport, channel narrowing, side channel habitat, backwater habitat, habitat maintenance
Pitlick et al. (1999)	Channel morphology, sediment transport, habitat formation, channel narrowing, peak-flow magnitude, peak-flow duration
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Van Steeter and Pitlick (1998)	Peak-flow magnitude, base-flow magnitude, sediment transport, channel narrowing, side channel habitat, backwater habitat
Loma to Westwater Canyon (Reach 5)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude

Table 6 (Cont.)

Reach/Citation	Attributes Studied
Loma to Westwater Canyon (Cont.)	
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Pitlick and Van Steeter (1998)	Peak-flow magnitude, sediment transport, channel narrowing, side channel habitat, backwater habitat, habitat maintenance
Pitlick et al. (1999)	Channel morphology, sediment transport, habitat formation, channel narrowing, peak-flow magnitude, peak-flow duration
Van Steeter and Pitlick (1998)	Peak-flow magnitude, base-flow magnitude, sediment transport, channel narrowing, side channel habitat, backwater habitat
Westwater Canyon (Reach 6)	
Chart and Lentsch (1999)	Humpback chub, habitat use, flow relationships
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
Trammel and Chart (1999b)	Colorado pikeminnow, spawning, juveniles, larvae, backwater habitat, habitat use, habitat availability, habitat formation, base-flow magnitude, peak-flow magnitude
Cottonwood Wash to Dewey Bridge (Reach 7)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Dewey Bridge to Hittle Bottom (Reach 8)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude

Table 6 (Cont.)

Reach/Citation	Attributes Studied
Dewey Bridge to Hittle Bottom (Cont.)	
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Hittle Bottom to White Rapid (Reach 9)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
White Rapid to Jackass Canyon (Reach 10)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Jackass Canyon to Moab Bridge (Reach 11)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude

Table 6 (Cont.)

Reach/Citation	Attributes Studied
Jackass Canyon to Moab Bridge (Cont.)	
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Trammel and Chart (1999b)	Colorado pikeminnow, spawning, juveniles, larvae, backwater habitat, habitat use, habitat availability, habitat formation, base-flow magnitude, peak-flow magnitude
Moab Bridge to Green River (Reach 12)	
Cooper and Severn (1994c)	Flooded bottomland habitat, habitat availability, peak-flow magnitude, water quality, restoration
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics
McAda (1993)	Backwater habitat, habitat availability, base-flow magnitude
McAda (2003)	Flow recommendations
McAda and Ryel (1999)	Colorado pikeminnow, spawning, larvae, juveniles, peak-flow magnitude, base-flow magnitude
Osmundson et al. (2002)	Channel morphology, sediment, sediment transport, bed characteristics, riffle/rapid habitat, run habitat, food base, peak-flow magnitude
Pucherelli et al. (1990b)	Backwater habitat, side channel habitat, habitat availability, base-flow magnitude
Pitlick and Cress (2000)	Channel morphology, sediment transport
Green River to Lake Powell (Reach 13)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
McAda (2003)	Flow recommendations
Gunnison River–Hartland Dam to Roubideau Creek (Reach 14)	
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
McAda (2003)	Flow recommendations
McAda and Fenton (1998)	Channel morphology, habitat availability, in-channel habitats, flooded bottomland habitat, peak-flow magnitude, base-flow magnitude
Gunnison River–Roubideau Creek to Colorado River (Reach 15)	
Anderson (1999)	Colorado pikeminnow, spawning, larvae, peak-flow magnitude
Burdick (1996)	Base-flow magnitude, Colorado pikeminnow, razorback sucker, passage
Cooper and Severn (1994b)	Flooded bottomland habitat, habitat availability, peak-flow magnitude, water quality, restoration
Irving and Burdick (1995)	Flooded bottomland habitat, habitat availability, peak-flow magnitude
Lamarra (1999)	In-channel habitats, habitat availability, food base, sediment, bed characteristics

Table 6 (Cont.)

Reach/Citation	Attributes Studied
Gunnison River–Roubideau Creek to Colorado River (Cont.)	
McAda (2003)	Flow recommendations, flooded bottomland habitat, habitat availability, peak-flow magnitude
McAda and Fenton (1998)	Channel morphology, habitat availability, in-channel habitats, flooded bottomland habitat, peak-flow magnitude, base-flow magnitude
Milhous (1998)	Sediment transport, bed characteristics, habitat maintenance, pool habitat, spawning habitat, side channel habitat, Colorado pikeminnow
Pitlick et al. (1999)	Channel morphology, sediment transport, channel narrowing, peak-flow magnitude, peak-flow duration
Dolores River	
Valdez et al. (1992)	Habitat availability

[a] Reach numbers correspond to locations in Figure 4. Dominant planform in reaches are given in Table 1.

Information about relationships among flow, channel morphology, and sediment transport in the upper Colorado River have been provided in studies by Osmundson et al. (2002), Pitlick and Cress (2000), Pitlick et al. (1999), Miller et al. (2002), Pitlick and Van Steeter (1998), and Van Steeter and Pitlick (1998). Sediment transport in the Gunnison River was investigated by Milhous (1998) and Pitlick et al. (1999). Some of these studies have looked at larger-scale sediment transport processes across a range of endangered fish habitats and in many reaches (e.g., Pitlick et al. 1999; Pitlick and Cress 2000; Osmundson et al. 2002), while others have focused in more detail on specific reaches and habitat types (e.g., Miller et al. 2002). Chart and Lentsch (1999) presented information about flow relationships and habitat use for various life stages of humpback chub in Westwater Canyon.

Research on flooded bottomland backwater nursery habitats has not been as extensive for the upper Colorado River subbasin as for the Green River subbasin, although several studies on the topic have been conducted. Even though little information is available about which floodplain areas might have historically served as nursery habitats for razorback suckers in the upper Colorado River and the Gunnison River, floodplain inventories and prioritizations have been conducted by Irving and Burdick (1995), and more specific floodplain habitat assessments have been conducted by Cooper and Severn (1994b,c) and McAda and Fenton (1998). Backwater availability and nursery habitat characteristics for Colorado pikeminnow in the upper Colorado River subbasin have been investigated by McAda (1993), Pucherelli et al. (1990b), McAda and Ryel (1999), and Trammell and Chart (1999b).

Specific spawning areas have not been identified for Colorado pikeminnow or razorback sucker in the upper Colorado River subbasin, and there are no studies that relate flow to spawning habitat characteristics for those species. However, successful reproduction by Colorado pikeminnow occurs every year, and it is suspected that spawning areas in the upper Colorado River are in meandering alluvial reaches (McAda 2003). Anderson (1999) and Trammel and Chart (1999b) related spawning success (based upon captures of drifting larvae) to spring flow levels.

5 RESULTS OF PRIORITY SCORING FOR REACHES AND HABITATS

This section presents the results of priority scoring of reach and habitat use for life stages of Colorado pikeminnow, humpback chub, and razorback sucker. The scores were developed with the methods described in Section 3. Relative levels of reach use by life stages of each species are presented in Tables 7, 8, and 9. Information about the relative use of different habitat types and the relative occurrence of various habitat types within each geomorphic planform are presented in Table 10. On the basis of the information in these tables, reach-habitat scores were calculated for each life stage of each species and for each species as a whole. These results are discussed in Sections 5.1, 5.2, and 5.3. Overall reach-habitat scores for all species combined are presented in Section 5.4. Scores for the same parameters, but based on potential levels of reach use, are presented in Appendix B.

Tables in Sections 5.1, 5.2, and 5.3 are color-coded to facilitate their interpretation. Table cells with reach-habitat scores that are ≥75% of the maximum score for the subbasin in a particular table are colored red; those that are ≥50% but <75% of the maximum are colored orange; those that are ≥25% but <50% of the maximum are colored yellow; and those that are <25% of the maximum are not colored. As described in Section 3, scores were developed separately for the Green River and upper Colorado River subbasins. Similarly, maximum values and subsequent cell coloring were determined separately.

5.1 COLORADO PIKEMINNOW

In the Green River subbasin, Colorado pikeminnow occur primarily from Lodore Canyon downstream to the confluence with the Colorado River. There is moderate to high use of the Green River by all life stages from Split Mountain Canyon to the confluence (Table 7). In addition, there is moderate to high use of some tributaries, especially the Yampa Canyon reach of the Yampa River. Colorado pikeminnow larvae scores are high in all reaches downstream of the spawning area in Yampa Canyon. Yampa Canyon and the Desolation and Gray Canyon reaches had high use scores for spawning, whereas other reaches were scored as no use. Adult use of the Yampa River was scored moderate to high, but juvenile use was scored low. Scores for tributaries reflect their limited use by any life stage; the exceptions were the high scores for subadult and adult use of the White River and moderate scores for the Duchesne River.

Fewer reaches in the upper Colorado River subbasin, received high scores than in the Green River subbasin (Table 7). Larval Colorado pikeminnow scored high in all reaches from the confluence with the Gunnison River to the confluence with the Green River. The highest scores for juvenile and subadult use in the upper Colorado River were for reaches downstream of the Moab Bridge, whereas those for adults were highest in the reaches just upstream and downstream of the confluence with the Gunnison River. Scores for adult fish, spawning, and larvae use were moderate in the lower reach of the Gunnison River (Roubideau Creek to the Colorado River confluence) and low or zero in the upper reach (Hartland Dam to Roubideau Creek). Use by juveniles or subadults in the Gunnison River has not been documented. The only other tributary to the upper Colorado River, the Dolores River, is little used by Colorado pikeminnow.

Table 7. Relative Use of Reaches by Life Stages of the Colorado Pikeminnow[a]

		Relative Use of Reach by Life Stage[b]				
	River/Reach	Larvae	Juvenile	Subadult	Adult	Spawning
I. Green River Subbasin						
Green River Mainstem						
1	Flaming Gorge Dam to Browns Park	0	0	0	0	0
2	Browns Park	0	0	0	1	0
3	Lodore Canyon	0	0	1	2	0
4	Yampa River to Island Park	3	0	2	3	0
5	Island and Rainbow Parks	3	1	2	3	0
6	Split Mountain Canyon	3	1	2	3	0
7	Split Mountain to Desolation Canyon	3	3	2	3	0
8	Desolation and Gray Canyons	3	2	3	3	3
9	Gray Canyon to Labyrinth Canyon	3	3	3	3	0
10	Labyrinth and Stillwater Canyons	3	3	3	3	0
Green River Tributaries						
11	Yampa River–Above Yampa Canyon	0	0	1	3	0
12	Yampa River–Yampa Canyon	3	1	2	2	3
	Little Snake River	0	0	0	1	0
	Duchesne River	0	1	2	2	0
	White River	0	1	3	3	0
	Price River	0	0	1	1	0
	San Rafael River	0	1	1	1	0
II. Upper Colorado River Subbasin						
Colorado River Mainstem						
1	Rulison to DeBeque Canyon	0	0	0	0	0
2	DeBeque Canyon to Palisade	0	0	0	0	0
3	Palisade to Gunnison River	1	1	1	3	1
4	Gunnison River to Loma	3	1	1	3	3
5	Loma to Westwater Canyon	3	1	1	2	3
6	Westwater Canyon	3	1	1	1	0
7	Cottonwood Wash to Dewey Bridge	3	1	1	2	3
8	Dewey Bridge to Hittle Bottom	3	2	1	1	0
9	Hittle Bottom to White Rapid	3	1	1	1	2
10	White Rapid to Jackass Canyon	3	1	1	1	0
11	Jackass Canyon to Moab Bridge	3	3	2	1	0
12	Moab Bridge to Green River	3	3	3	1	0
13	Green River to Lake Powell	2	3	2	1	0
Colorado River Tributaries						
14	Gunnison R.–Hartland to Roubideau	0	0	0	1	0
15	Gunnison R.–Roubideau to Colorado R.	2	0	0	2	2
	Dolores River	0	0	0	1	0

[a] See Section 3 for reach and life-stage definitions.

[b] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

Table 8. Relative Use of Reaches by Life Stages of the Humpback Chub[a]

	Relative Use of Reach by Life Stage[b]				
River/Reach	Larvae	Juvenile	Subadult	Adult	Spawning
I. Green River Subbasin					
Green River Mainstem					
1 Flaming Gorge Dam to Browns Park	0	0	0	0	0
2 Browns Park	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0
4 Yampa River to Island Park	1	1	1	1	1
5 Island and Rainbow Parks	0	0	0	0	0
6 Split Mountain Canyon	1	1	1	1	1
7 Split Mountain to Desolation Canyon	0	0	0	1	0
8 Desolation and Gray Canyons	3	3	3	3	3
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0
Green River Tributaries					
11 Yampa River–Above Yampa Canyon	0	0	0	1	0
12 Yampa River–Yampa Canyon	2	2	2	2	2
Little Snake River	0	0	0	1	0
Duchesne River	0	0	0	0	0
White River	0	0	0	0	0
Price River	0	0	0	0	0
San Rafael River	0	0	0	0	0
II. Upper Colorado River Subbasin					
Colorado River Mainstem					
1 Rulison to DeBeque Canyon	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0
5 Loma to Westwater Canyon	3	3	3	3	3
6 Westwater Canyon	3	3	3	3	3
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0
13 Green River to Lake Powell	2	2	2	2	2
Colorado River Tributaries					
14 Gunnison R.–Hartland to Roubideau	0	0	0	0	0
15 Gunnison R.–Roubideau to Colorado R.	0	0	0	1	0
Dolores River	0	0	0	0	0

[a] See Section 3 for reach and life-stage definitions.

[b] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

Table 9. Relative Use of Reaches by Life Stages of the Razorback Sucker[a]

River/Reach	Relative Use of Reach by Life Stage[b]				
	Larvae	Juvenile	Subadult	Adult	Spawning
I. Green River Subbasin					
Green River Mainstem					
1 Flaming Gorge Dam to Browns Park	0	0	0	0	0
2 Browns Park	0	0	0	0	0
3 Lodore Canyon	0	0	1	1	0
4 Yampa River to Island Park	2	0	2	2	1
5 Island and Rainbow Parks	2	0	2	2	0
6 Split Mountain Canyon	2	0	2	2	1
7 Split Mountain to Desolation Canyon	3	3	3	3	3
8 Desolation and Gray Canyons	1	0	2	2	1
9 Gray Canyon to Labyrinth Canyon	3	3	1	1	2
10 Labyrinth and Stillwater Canyons	3	3	1	1	0
Green River Tributaries					
11 Yampa River–Above Yampa Canyon	0	0	0	0	0
12 Yampa River–Yampa Canyon	2	0	1	1	2
Little Snake River	0	0	0	0	0
Duchesne River	1	1	2	2	1
White River	0	0	1	1	0
Price River	0	0	0	0	0
San Rafael River	3	3	1	1	0
II. Upper Colorado River Subbasin					
Colorado River Mainstem					
1 Rulison to DeBeque Canyon	0	0	0	3	3
2 DeBeque Canyon to Palisade	0	0	1	1	0
3 Palisade to Gunnison River	0	0	0	3	3
4 Gunnison River to Loma	0	0	0	3	3
5 Loma to Westwater Canyon	0	0	0	1	0
6 Westwater Canyon	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	1
13 Green River to Lake Powell	0	0	0	0	0
Colorado River Tributaries					
14 Gunnison R.–Hartland to Roubideau	1	0	1	1	1
15 Gunnison R.–Roubideau to Colorado R.	1	0	1	1	1
Dolores River	0	0	0	0	0

[a] See Section 3 for reach and life-stage definitions.

[b] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

Table 10. Relative Occurrence and Use of Habitats by Colorado Pikeminnow, Humpback Chub, and Razorback Sucker Life Stages in Different Planform Types[a]

Planform/Habitats Types	Relative Occurrence of Habitat Type[b]	Relative Use of Habitat in Planform[c]											
		Colorado Pikeminnow				Humpback Chub				Razorback Sucker			
		Larvae	Juvenile	Subadult	Adult	Larvae	Juvenile	Subadult	Adult	Larvae	Juvenile	Subadult	Adult
I. Canyons													
Main channel habitats													
Pools	3	1	1	3	3	1	0	2	2	1	1	3	3
Runs	3	1	1	3	3	1	3	2	1	1	1	3	3
Riffles/rapids	3	1	1	2	2	1	0	0	0	1	1	2	2
Channel margin habitats													
Connected backwaters	1	1	1	1	1	2	2	2	1	1	1	2	2
Side channels	1	1	1	1	1	2	2	2	1	1	1	2	2
Eddies	3	1	1	3	3	2	2	3	3	1	1	3	3
Flooded tributary mouths	1	1	1	3	3	2	2	2	2	1	1	3	3
Off-channel habitats													
Flooded bottomlands	0	1	1	1	1	0	0	0	0	1	1	1	1
II. Restricted meanders													
Main channel habitats													
Pools	2	1	1	3	3	1	0	1	1	1	1	3	3
Runs	3	1	1	3	3	1	1	1	1	1	1	3	3
Riffles/rapids	2	1	1	1	1	1	0	0	0	1	1	1	1
Channel margin habitats													
Connected backwaters	3	3	3	2	2	1	1	1	1	2	2	2	2
Side channels	3	2	2	2	2	1	1	1	1	2	2	2	2
Eddies	2	1	1	3	3	1	1	1	1	1	1	3	3
Flooded tributary mouths	3	2	2	3	3	1	1	1	1	2	2	3	3
Off-channel habitats													
Flooded bottomlands	3	1	1	2	2	0	0	0	0	3	3	3	3

Table 10 (Continued)

Planform/Habitats Types[a]	Relative Occurrence of Habitat Type[b]	Relative Use of Habitat in Planform[c]											
		Colorado Pikeminnow				Humpback Chub				Razorback Sucker			
		Larvae	Juvenile	Subadult	Adult	Larvae	Juvenile	Subadult	Adult	Larvae	Juvenile	Subadult	Adult
III. Fixed meanders													
Main channel habitats													
Pools	3	1	1	3	3	1	0	1	1	1	1	3	3
Runs	3	1	1	3	3	1	1	1	1	1	1	3	3
Riffles/rapids	3	1	1	1	1	1	0	0	1	1	1	1	1
Channel margin habitats													
Connected backwaters	3	3	3	2	2	1	1	1	1	2	2	3	3
Side channels	3	2	2	2	2	1	1	1	1	2	2	2	2
Eddies	3	1	1	2	2	1	1	1	1	1	1	3	3
Flooded tributary mouths	2	2	2	3	3	1	1	1	1	2	2	3	3
Off-channel habitats													
Flooded bottomlands	1	1	1	1	1	0	0	0	0	2	2	2	2

[a] See Section 3 for definitions of planforms, habitats, and life stages.

[b] 0 = not found, 1 = low occurrence, 2 = moderate occurrence, 3 = high occurrence.

[c] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

The relative occurrence in different habitat types by the various life stages of Colorado pikeminnow is presented in Table 10. Adult fish preferentially use main-channel habitats in all three planform types (canyons, restricted meanders, and fixed meanders), while use of main channel habitats by larvae and juveniles is low in all planform types. Use of channel-margin habitats in both restricted and fixed meanders is moderate to high for most life stages, with high use of connected backwaters by larvae and juveniles. There is moderate to high use of flooded tributary mouths by subadult and adult Colorado pikeminnow in all three planform types.

Scores for reach use (Table 7), habitat use (Table 10), and the relative occurrence of each habitat type in different planforms (Table 10) were used to compute reach-habitat scores for each life stage (see Section 3). Reach-habitat scores for Colorado pikeminnow larvae in the Green River subbasin were highest for backwater habitats in restricted- and fixed-meander reaches (Island and Rainbow Parks, Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, and Labyrinth and Stillwater Canyons) that are downstream of spawning areas in the Yampa River and on the mainstem Green River (Table 11). Similarly, the highest scores for larvae in the upper Colorado River subbasin were for backwater habitats in restricted- and fixed-meander reaches (Table 11). The next highest reach-habitat scores for larval Colorado pikeminnow in both the Green and Colorado Rivers were for side channels and flooded tributary mouths in the same reaches (Table 11).

For juvenile Colorado pikeminnow, the highest reach-habitat scores were for backwater habitats in restricted- and fixed-meander reaches in the downstream portions of both the Green River (Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, and Labyrinth and Stillwater Canyons) and the Colorado River (Jackass Canyon to Moab Bridge and Moab Bridge to Green River). The next highest set of reach-habitat scores for juvenile Colorado pikeminnow were for backwaters in the Dewey Bridge to Hittle Bottom reach, and for side channels and flooded tributary mouths in most reaches with high-scoring backwater habitat (Table 12).

The highest reach-habitat scores for subadult Colorado pikeminnow were for pools, runs, eddies, and flooded tributary mouths (Table 13). Backwater, side channel, and flooded bottomland habitats in some reaches were in the second-tier of reach-habitat scores (50-75% of the maximum score). This included the use of run and flooded tributary mouth habitat associated with the White River in the Green River subbasin. In the upper Colorado River subbasin, the higher-scoring habitats tended to be in downstream reaches, especially the Moab Bridge to Green River reach.

The use of canyon habitats by adult Colorado pikeminnow in the Green River is reflected in higher reach-habitat scores for pools and eddies in canyon-bound reaches for this life stage (Table 14). In addition, reach-habitat scores were high for run habitat in nearly all reaches of the Green River. In the upper Colorado River subbasin, the highest reach-habitat scores for adult Colorado pikeminnow were for runs and flooded tributary mouths in reaches just upstream and downstream of the confluence with the Gunnison River.

Table 11. Reach-Habitat Scores for Colorado Pikeminnow Larvae

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	9	9	9	3	3	9	3	0
5 Island and Rainbow Parks	6	9	6	27	18	6	18	9
6 Split Mountain Canyon	9	9	9	3	3	9	3	0
7 Split Mt. to Desolation Canyon	6	9	6	27	18	6	18	9
8 Desolation and Gray Canyons	9	9	9	3	3	9	3	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	27	18	6	18	9
10 Labyrinth and Stillwater Canyons	9	9	9	27	18	9	12	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	9	3	3	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	2	3	2	9	6	2	6	3
4 Gunnison River to Loma	6	9	6	27	18	6	18	9
5 Loma to Westwater Canyon	9	9	9	27	18	9	12	3
6 Westwater Canyon	9	9	9	3	3	9	3	0
7 Cottonwood Wash to Dewey Bridge	6	9	6	27	18	6	18	9
8 Dewey Bridge to Hittle Bottom	9	9	9	27	18	9	12	3
9 Hittle Bottom to White Rapid	6	9	6	27	18	6	18	9
10 White Rapid to Jackass Canyon	9	9	9	27	18	9	12	3
11 Jackass Canyon to Moab Bridge	9	9	9	27	18	9	12	3
12 Moab Bridge to Green River	9	9	9	27	18	9	12	3
13 Green River to Lake Powell	6	6	6	2	2	6	2	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	6	6	6	18	12	6	8	2
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: ≥ 75% of maximum for subbasin, red; 50%–75% of maximum, orange, 25%–50% of maximum, yellow.

Table 12. Reach-Habitat Scores for Colorado Pikeminnow Juveniles

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	0	0	0	0	0	0	0	0
5 Island and Rainbow Parks	2	3	2	9	6	2	6	3
6 Split Mountain Canyon	3	3	3	1	1	3	1	0
7 Split Mt. to Desolation Canyon	6	9	6	27	18	6	18	9
8 Desolation and Gray Canyons	6	6	6	2	2	6	2	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	27	18	6	18	9
10 Labyrinth and Stillwater Canyons	9	9	9	27	18	9	12	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	3	3	3	1	1	3	1	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	2	3	2	9	6	2	6	3
White River	2	3	2	9	6	2	6	3
Price River	0	0	0	0	0	0	0	0
San Rafael River	2	3	2	9	6	2	6	3
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	2	3	2	9	6	2	6	3
4 Gunnison River to Loma	2	3	2	9	6	2	6	3
5 Loma to Westwater Canyon	3	3	3	9	6	3	4	1
6 Westwater Canyon	3	3	3	1	1	3	1	0
7 Cottonwood Wash to Dewey Bridge	2	3	2	9	6	2	6	3
8 Dewey Bridge to Hittle Bottom	6	6	6	18	12	6	8	2
9 Hittle Bottom to White Rapid	2	3	2	9	6	2	6	3
10 White Rapid to Jackass Canyon	3	3	3	9	6	3	4	1
11 Jackass Canyon to Moab Bridge	9	9	9	27	18	9	12	3
12 Moab Bridge to Green River	9	9	9	27	18	9	12	3
13 Green River to Lake Powell	9	9	9	3	3	9	3	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 13. Reach-Habitat Scores for Colorado Pikeminnow Subadults

River/Reach	Reach-Habitat Score[a] Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	9	9	6	1	1	9	3	0
4 Yampa River to Island Park	18	18	12	2	2	18	6	0
5 Island and Rainbow Parks	12	18	4	12	12	12	18	12
6 Split Mountain Canyon	18	18	12	2	2	18	6	0
7 Split Mt. to Desolation Canyon	12	18	4	12	12	12	18	12
8 Desolation and Gray Canyons	27	27	18	3	3	27	9	0
9 Gray Canyon to Labyrinth Canyon	18	27	6	18	18	18	27	18
10 Labyrinth and Stillwater Canyons	27	27	9	18	18	18	18	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	6	9	2	6	6	6	9	6
12 Yampa–Yampa Canyon	18	18	12	2	2	18	6	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	12	18	4	12	12	12	18	12
White River	18	27	6	18	18	18	27	18
Price River	9	9	3	6	6	6	6	1
San Rafael River	6	9	2	6	6	6	9	6
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	6	9	2	6	6	6	9	6
4 Gunnison River to Loma	6	9	2	6	6	6	9	6
5 Loma to Westwater Canyon	9	9	3	6	6	6	6	1
6 Westwater Canyon	9	9	6	1	1	9	3	0
7 Cottonwood Wash to Dewey Bridge	6	9	2	6	6	6	9	6
8 Dewey Bridge to Hittle Bottom	9	9	3	6	6	6	6	1
9 Hittle Bottom to White Rapid	6	9	2	6	6	6	9	6
10 White Rapid to Jackass Canyon	9	9	3	6	6	6	6	1
11 Jackass Canyon to Moab Bridge	18	18	6	12	12	12	12	2
12 Moab Bridge to Green River	27	27	9	18	18	18	18	3
13 Green River to Lake Powell	18	18	12	2	2	18	6	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 14. Reach-Habitat Scores for Colorado Pikeminnow Adults

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	6	9	2	6	6	6	9	6
3 Lodore Canyon	18	18	12	2	2	18	6	0
4 Yampa River to Island Park	27	27	18	3	3	27	9	0
5 Island and Rainbow Parks	18	27	6	18	18	18	27	18
6 Split Mountain Canyon	27	27	18	3	3	27	9	0
7 Split Mt. to Desolation Canyon	18	27	6	18	18	18	27	18
8 Desolation and Gray Canyons	27	27	18	3	3	27	9	0
9 Gray Canyon to Labyrinth Canyon	18	27	6	18	18	18	27	18
10 Labyrinth and Stillwater Canyons	27	27	9	18	18	18	18	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	18	27	6	18	18	18	27	18
12 Yampa–Yampa Canyon	18	18	12	2	2	18	6	0
Little Snake River	6	9	2	6	6	6	9	6
Duchesne River	12	18	4	12	12	12	18	12
White River	18	27	6	18	18	18	27	18
Price River	9	9	3	6	6	6	6	1
San Rafael River	6	9	2	6	6	6	9	6
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	18	27	6	18	18	18	27	18
4 Gunnison River to Loma	18	27	6	18	18	18	27	18
5 Loma to Westwater Canyon	18	18	6	12	12	12	12	2
6 Westwater Canyon	9	9	6	1	1	9	3	0
7 Cottonwood Wash to Dewey Bridge	12	18	4	12	12	12	18	12
8 Dewey Bridge to Hittle Bottom	9	9	3	6	6	6	6	1
9 Hittle Bottom to White Rapid	6	9	2	6	6	6	9	6
10 White Rapid to Jackass Canyon	9	9	3	6	6	6	6	1
11 Jackass Canyon to Moab Bridge	9	9	3	6	6	6	6	1
12 Moab Bridge to Green River	9	9	3	6	6	6	6	1
13 Green River to Lake Powell	9	9	6	1	1	9	3	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	6	9	2	6	6	6	9	6
15 Gunnison–Roubideau to Colorado	18	18	6	12	12	12	12	2
Dolores River	9	9	3	6	6	6	6	1

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Overall reach-habitat scores for Colorado pikeminnow (i.e., the sum of weighted life-stage scores) were highest for backwater, side channel, and flooded tributary mouth habitats in the Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, and Labyrinth and Stillwater Canyon reaches of the Green River (Table 15). The high scores reflect the importance of these two reaches and these three habitat types for several life stages of the Colorado pikeminnow. In the upper Colorado River subbasin, the highest overall reach-habitat scores for Colorado pikeminnow were for backwaters in the Jackass Canyon to Moab Bridge and Moab Bridge to Green River reaches. Only two spawning areas, both high use, occur in the Green River subbasin (Desolation and Gray Canyon and Yampa Canyon reaches; Table 15). In the upper Colorado River subbasin, the Gunnison River to Loma, Loma to Westwater Canyon, and Cottonwood Wash to Dewey Bridge reaches had the highest scores for spawning habitat.

5.2 HUMPBACK CHUB

Reach-use scores for the humpback chub reflect this species' high fidelity to canyons in all life stages (Table 8). In the Green River subbasin, the Desolation and Gray Canyons reach was scored as high use, and the Yampa Canyon reach in the Yampa River was scored as moderate use. The Yampa River to Island Park reach and the Split Mountain Canyon reach in the Green River were scored as low use by all life stages of the humpback chub. In addition, there is low use of the Yampa River above Yampa Canyon and the Little Snake River by adult humpback chub. In the upper Colorado River subbasin, high scores were assigned to the Loma to Westwater Canyon reach, which includes Black Rocks, and to the Westwater Canyon reach; moderate-use scores were assigned for all life stages in the Green River to Lake Powell reach (includes Cataract Canyon). Few humpback chub of any life stage have been found in tributaries to the upper Colorado River.

Life stages of the humpback chub differ somewhat in their use of different habitats (Table 10). In canyons, humpback chub larvae primarily use channel-margin habitats; main-channel pool, run, and riffle/rapid habitat types are also used, but to a lesser extent. There is high use of run habitats in the main channel by juvenile humpback chub and moderate use of channel margin habitats. The use of eddies by subadult and adult humpback chub was scored high. While there is only low use of backwaters and side channels by adult humpback chub, there is moderate use of such habitat types by subadult fish. In canyons, where humpback chub are almost exclusively found, there is a high occurrence of pools, runs, and riffles/rapids in the main channel and eddies along the channel margins (Table 10). Backwaters, side channels, and flooded tributary mouths have a low occurrence in canyon reaches. Use values for all habitats in other planform types are low and reflect the fidelity of this species to canyons.

Reach-habitat scores for larval humpback chub were highest for eddy habitat in the reaches where humpback chub have the greatest occurrence (Desolation and Gray Canyons in the Green River and the Loma to Westwater Canyon (Black Rocks portion) and Westwater Canyon reaches of the Colorado River; Table 16). Reach-habitat scores for juveniles (Table 17) were highest for runs in the same reaches, with eddies in those reaches falling into the second tier of reach-habitat scores (i.e., 50% to 75% of the maximum score). Reach-habitat scores for

Table 15. Reach-Habitat Scores for All Colorado Pikeminnow Life Stages Combined

River/Reach	Reach-Habitat Score[a]								
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	6	9	2	6	6	6	9	6	0
3 Lodore Canyon	27	27	18	3	3	27	9	0	0
4 Yampa River to Island Park	54	54	39	8	8	54	18	0	0
5 Island and Rainbow Parks	42	63	22	84	66	42	81	48	0
6 Split Mountain Canyon	63	63	48	11	11	63	21	0	0
7 Split Mt. to Desolation Canyon	54	81	34	138	102	54	117	66	0
8 Desolation and Gray Canyons	81	81	63	15	15	81	27	0	3
9 Gray Canyon to Labyrinth Canyon	60	90	36	144	108	60	126	72	0
10 Labyrinth and Stillwater Canyons	90	90	54	144	108	72	84	18	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	24	36	8	24	24	24	36	24	0
12 Yampa–Yampa Canyon	54	54	42	10	10	54	18	0	3
Little Snake River	6	9	2	6	6	6	9	6	0
Duchesne River	30	45	14	51	42	30	54	33	0
White River	42	63	18	63	54	42	72	45	0
Price River	18	18	6	12	12	12	12	2	0
San Rafael River	18	27	10	39	30	18	36	21	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	32	48	16	60	48	32	60	36	1
4 Gunnison River to Loma	36	54	20	78	60	36	72	42	3
5 Loma to Westwater Canyon	45	45	27	72	54	36	42	9	3
6 Westwater Canyon	36	36	30	8	8	36	12	0	0
7 Cottonwood Wash to Dewey Bridge	30	45	18	72	54	30	63	36	3
8 Dewey Bridge to Hittle Bottom	45	45	33	93	66	39	48	11	0
9 Hittle Bottom to White Rapid	24	36	16	66	48	24	54	30	2
10 White Rapid to Jackass Canyon	36	36	24	66	48	30	36	8	0
11 Jackass Canyon to Moab Bridge	63	63	45	126	90	54	66	15	0
12 Moab Bridge to Green River	72	72	48	132	96	60	72	16	0
13 Green River to Lake Powell	60	60	51	14	14	60	20	0	0
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	6	9	2	6	6	6	9	6	0
15 Gunnison–Roubideau to Colorado	24	24	12	30	24	18	20	4	2
Dolores River	9	9	3	6	6	6	6	1	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each life stage (Tables 11 to 14) were multiplied by life-stage weight and weighted scores summed for each reach-habitat combination. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum. Scores for spawning bar complexes are based only on reach use (Table 7).

Table 16. Reach-Habitat Scores for Humpback Chub Larvae

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	3	3	3	2	2	6	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	3	3	3	2	2	6	2	0
7 Split Mt. to Desolation Canyon	0	0	0	0	0	0	0	0
8 Desolation and Gray Canyons	9	9	9	6	6	18	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	6	6	6	4	4	12	4	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	9	9	9	6	6	18	6	0
6 Westwater Canyon	9	9	9	6	6	18	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	6	6	6	4	4	12	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 17. Reach-Habitat Scores for Humpback Chub Juveniles

	Reach-Habitat Score[a]							
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	0	9	0	2	2	6	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	0	9	0	2	2	6	2	0
7 Split Mt. to Desolation Canyon	0	0	0	0	0	0	0	0
8 Desolation and Gray Canyons	0	27	0	6	6	18	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	0	18	0	4	4	12	4	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	0	27	0	6	6	18	6	0
6 Westwater Canyon	0	27	0	6	6	18	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	0	18	0	4	4	12	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

subadults (Table 18) and adults (Table 19) were highest for eddy habitat in those same reaches, followed by pool and run habitats. Overall reach-habitat scores (i.e., the sum of weighted life-stage scores) were highest for eddy and run habitats in the Desolation and Gray Canyons reach in the Green River and for the Loma to Westwater Canyon (Black Rocks portion) and Westwater Canyon reaches in the Colorado River (Table 20).

5.3 RAZORBACK SUCKER

Relative use of reaches by all life stages of the razorback sucker are presented in Table 9. In the Green River subbasin, high-use scores were assigned to the Split Mountain Canyon to Desolation Canyon reach for all life stages. High-use scores were also assigned to the Gray Canyon to Labyrinth Canyon and Labyrinth and Stillwater Canyon reaches for larvae and juveniles. Moderate-use scores were assigned to larvae in Green River reaches downstream of the spawning area located near the mouth of the Yampa River. Subadults and adults also were assigned moderate-use-scores for these reaches. High scores were assigned to larval and juvenile use of the San Rafael River, where these life stages have been captured at the tributary mouth. Use of Green River tributaries by subadults and adults is moderate in the Duchesne River and low in the White and San Rafael Rivers. The highest use spawning area in the Green River subbasin is located in the Split Mountain Canyon to Desolation Canyon reach; there is moderate use of the Yampa Canyon reach of the Yampa River for spawning.

Even though the number of razorback suckers in the upper Colorado River subbasin is currently very low, evidence obtained during the past two decades indicates that the areas with the highest relative use occur in the Rulison to DeBeque Canyon, Palisade to Gunnison River, and Gunnison River to Loma reaches (Table 9). These reaches are also considered the highest use areas for spawning in the upper Colorado River subbasin despite the fact that little or no larval production has been documented recently. Except for the DeBeque Canyon to Palisade reach, where there is low use by subadult fish, there is no use of the mainstem upper Colorado River by larvae, juvenile, or subadult razorback suckers, indicating the lack of reproduction in the system. The Gunnison River has low use by larval, subadult, and adult razorback suckers and is considered to have low use for spawning (a few larval fish were found in 2003). Existing levels of use reflect population augmentation efforts that have occurred since the middle 1990s.

A wide variety of habitat types in all three river planform categories are used frequently by subadult and adult razorback suckers (Table 10). Such habitats include main-channel, channel-margin, and off-channel habitats. In contrast, larvae and juveniles primarily use channel-margin and off-channel habitats in restricted- and fixed-meander reaches. For larvae and juveniles, flooded bottomlands in restricted-meander reaches had the highest use scores, while flooded tributary mouths, side channels, and backwaters in both restricted- and fixed-meander reaches had moderate scores. Main channel habitats (pools, runs, and riffles/rapids) and eddies are little used by these life stages (Table 10).

Reach-habitat scores for larval razorback suckers in the Green River subbasin were highest for flooded bottomland habitat in the Split Mountain Canyon to Desolation Canyon

Table 18. Reach-Habitat Scores for Humpback Chub Subadults

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	6	6	0	2	2	9	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	6	6	0	2	2	9	2	0
7 Split Mt. to Desolation Canyon	0	0	0	0	0	0	0	0
8 Desolation and Gray Canyons	18	18	0	6	6	27	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	12	12	0	4	4	18	4	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	18	18	0	6	6	27	6	0
6 Westwater Canyon	18	18	0	6	6	27	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	12	12	0	4	4	18	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 19. Reach-Habitat Scores for Humpback Chub Adults

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	6	3	0	1	1	9	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	6	3	0	1	1	9	2	0
7 Split Mt. to Desolation Canyon	2	3	0	3	3	2	3	0
8 Desolation and Gray Canyons	18	9	0	3	3	27	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	2	3	0	3	3	2	3	0
12 Yampa–Yampa Canyon	12	6	0	2	2	18	4	0
Little Snake River	2	3	0	3	3	2	3	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	18	9	0	3	3	27	6	0
6 Westwater Canyon	18	9	0	3	3	27	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	12	6	0	2	2	18	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	3	3	0	3	3	3	2	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 20. Reach-Habitat Scores for All Humpback Chub Life Stages Combined

	Reach-Habitat Score[a]								
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	15	30	3	9	9	36	10	0	1
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	15	30	3	9	9	36	10	0	1
7 Split Mt. to Desolation Canyon	2	3	0	3	3	2	3	0	0
8 Desolation and Gray Canyons	45	90	9	27	27	108	30	0	3
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	2	3	0	3	3	2	3	0	0
12 Yampa–Yampa Canyon	30	60	6	18	18	72	20	0	2
Little Snake River	2	3	0	3	3	2	3	0	0
Duchesne River	0	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	45	90	9	27	27	108	30	0	3
6 Westwater Canyon	45	90	9	27	27	108	30	0	3
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	30	60	6	18	18	72	20	0	2
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	3	3	0	3	3	3	2	0	0
Dolores River	0	0	0	0	0	0	0	0	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each life stage (Tables 16 to 19) were multiplied by life-stage weight and weighted scores summed for each reach-habitat combination. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum. Scores for spawning bar complexes are based only on reach use (Table 8).

reach, the Gray Canyon to Labyrinth Canyon reach, and the mouth of the San Rafael River (Table 21). The second-highest reach-habitat scores for larval razorback suckers in the Green River subbasin were for backwater, side channel, and flooded tributary mouth habitat in these same reaches. In the upper Colorado River subbasin, reach-habitat scores for larval razorback suckers were highest for flooded bottomland habitat in the Hartland Dam to Roubideau Creek reach of the Gunnison River, followed by backwater, side channel, and flooded tributary mouth habitat in the same reach. These relatively high scores reflect the lack of larvae elsewhere in the system rather than high use in these habitats in this particular reach.

Flooded bottomland habitat in the Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon reaches, and in the San Rafael River had the highest reach-habitat scores for juvenile razorback suckers in the Green River subbasin (Table 22). No razorback sucker juveniles have been documented recently in the upper Colorado River subbasin (Tables 9 and 22).

Reach-habitat scores for subadult razorback sucker in the Green River subbasin were highest for run, flooded tributary mouth, and flooded bottomland habitat in the Split Mountain Canyon to Desolation Canyon reach (Table 23). The next highest scores for this subbasin and life stage were for pool, run, and eddy habitats in the reaches from the Yampa River to Desolation and Gray Canyons, for backwater and side channel habitats in the Split Mountain Canyon to Desolation Canyon Reach, and for flooded tributary mouth and flooded bottomland habitat in the Island and Rainbow Parks reach and the Duchesne River. The highest reach-habitat scores for subadult razorback suckers in the upper Colorado River subbasin were for pool, run, and eddy habitats in the DeBeque Canyon to Palisade Reach; high reach-habitat scores were also indicated for pool, run, eddy, flooded tributary mouth, and flooded bottomland habitats in the Gunnison River reaches (Table 23). Gunnison River scores reflect use levels by fish stocked since the middle 1990s and are relatively high because of the paucity of fish elsewhere in the system.

Reach-habitat scores for adult razorback suckers in the Green River subbasin (Table 24) were identical to those described for subadults in the previous paragraph. In the upper Colorado River subbasin, the highest reach-habitat scores were for runs, flooded tributary mouth, and flooded bottomland habitat in the Rulison to DeBeque Canyon, Palisade to Gunnison River, and Gunnison River to Loma reaches (Table 24). The next highest scores were for pool, backwater, side channel, and eddy habitats in the same reaches.

Overall reach-habitat scores for razorback suckers in the Green River subbasin were highest for flooded tributary mouth and flooded bottomland habitats in the Split Mountain Canyon to Desolation Canyon reach and for flooded bottomland habitat in the Gray Canyon to Labyrinth Canyon reach and the San Rafael River (Table 25). The highest scores for spawning habitat in the Green River subbasin were in the Split Mountain Canyon to Desolation Canyon reach, followed by the Gray Canyon to Labyrinth Canyon reach and Yampa Canyon. In the upper Colorado River subbasin, the highest overall reach-habitat scores were for pool, flooded tributary mouth, and flooded bottomland habitats in the Rulison to DeBeque Canyon, Palisade to Gunnison River, and Gunnison River to Loma reaches (Table 25). The highest overall reach-habitat scores for spawning habitat in the upper Colorado River subbasin were for these same three reaches. In the Gunnison River, the highest overall reach-habitat scores were for pool, run, eddy, flooded tributary mouth, and flooded bottomland habitats.

Table 21. Reach-Habitat Scores for Razorback Sucker Larvae

	Reach-Habitat Score[a]							
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	6	6	6	2	2	6	2	0
5 Island and Rainbow Parks	4	6	4	12	12	4	12	18
6 Split Mountain Canyon	6	6	6	2	2	6	2	0
7 Split Mt. to Desolation Canyon	6	9	6	18	18	6	18	27
8 Desolation and Gray Canyons	3	3	3	1	1	3	1	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	18	18	6	18	27
10 Labyrinth and Stillwater Canyons	9	9	9	18	18	9	12	6
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	6	6	6	2	2	6	2	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	2	3	2	6	6	2	6	9
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	6	18	18	6	18	27
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	0	0	0	0	0	0	0	0
6 Westwater Canyon	0	0	0	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	2	3	2	6	6	2	6	9
15 Gunnison–Roubideau to Colorado	3	3	3	6	6	3	4	2
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 22. Reach-Habitat Scores for Razorback Sucker Juveniles

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	0	0	0	0	0	0	0	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	0	0	0	0	0	0	0	0
7 Split Mt. to Desolation Canyon	6	9	6	18	18	6	18	27
8 Desolation and Gray Canyons	0	0	0	0	0	0	0	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	18	18	6	18	27
10 Labyrinth and Stillwater Canyons	9	9	9	18	18	9	12	6
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	0	0	0	0	0	0	0	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	2	3	2	6	6	2	6	9
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	6	18	18	6	18	27
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	0	0	0	0	0	0	0	0
6 Westwater Canyon	0	0	0	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 23. Reach-Habitat Scores for Razorback Sucker Subadults

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	9	9	6	2	2	9	3	0
4 Yampa River to Island Park	18	18	12	4	4	18	6	0
5 Island and Rainbow Parks	12	18	4	12	12	12	18	18
6 Split Mountain Canyon	18	18	12	4	4	18	6	0
7 Split Mt. to Desolation Canyon	18	27	6	18	18	18	27	27
8 Desolation and Gray Canyons	18	18	12	4	4	18	6	0
9 Gray Canyon to Labyrinth Canyon	6	9	2	6	6	6	9	9
10 Labyrinth and Stillwater Canyons	9	9	3	9	6	9	6	2
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	6	2	2	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	12	18	4	12	12	12	18	18
White River	6	9	2	6	6	6	9	9
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	2	6	6	6	9	9
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	9	9	3	9	6	9	6	2
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	0	0	0	0	0	0	0	0
6 Westwater Canyon	0	0	0	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	6	9	2	6	6	6	9	9
15 Gunnison–Roubideau to Colorado	9	9	3	9	6	9	6	2
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 24. Reach-Habitat Scores for Razorback Sucker Adults

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	9	9	6	2	2	9	3	0
4 Yampa River to Island Park	18	18	12	4	4	18	6	0
5 Island and Rainbow Parks	12	18	4	12	12	12	18	18
6 Split Mountain Canyon	18	18	12	4	4	18	6	0
7 Split Mt. to Desolation Canyon	18	27	6	18	18	18	27	27
8 Desolation and Gray Canyons	18	18	12	4	4	18	6	0
9 Gray Canyon to Labyrinth Canyon	6	9	2	6	6	6	9	9
10 Labyrinth and Stillwater Canyons	9	9	3	9	6	9	6	2
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	6	2	2	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	12	18	4	12	12	12	18	18
White River	6	9	2	6	6	6	9	9
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	2	6	6	6	9	9
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	18	27	6	18	18	18	27	27
2 DeBeque Canyon to Palisade	9	9	3	9	6	9	6	2
3 Palisade to Gunnison River	18	27	6	18	18	18	27	27
4 Gunnison River to Loma	18	27	6	18	18	18	27	27
5 Loma to Westwater Canyon	9	9	3	9	6	9	6	2
6 Westwater Canyon	0	0	0	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	6	9	2	6	6	6	9	9
15 Gunnison–Roubideau to Colorado	9	9	3	9	6	9	6	2
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table 25. Reach-Habitat Scores for All Razorback Sucker Life Stages Combined

River/Reach	Reach-Habitat Score[a]								
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0	0
3 Lodore Canyon	18	18	12	4	4	18	6	0	0
4 Yampa River to Island Park	42	42	30	10	10	42	14	0	1
5 Island and Rainbow Parks	28	42	12	36	36	28	48	54	0
6 Split Mountain Canyon	42	42	30	10	10	42	14	0	1
7 Split Mt. to Desolation Canyon	60	90	36	108	108	60	126	162	3
8 Desolation and Gray Canyons	39	39	27	9	9	39	13	0	1
9 Gray Canyon to Labyrinth Canyon	36	54	28	84	84	36	90	126	2
10 Labyrinth and Stillwater Canyons	54	54	42	90	84	54	60	28	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	24	24	18	6	6	24	8	0	2
Little Snake River	0	0	0	0	0	0	0	0	0
Duchesne River	32	48	16	48	48	32	60	72	1
White River	12	18	4	12	12	12	18	18	0
Price River	0	0	0	0	0	0	0	0	0
San Rafael River	36	54	28	84	84	36	90	126	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	18	27	6	18	18	18	27	27	3
2 DeBeque Canyon to Palisade	18	18	6	18	12	18	12	4	0
3 Palisade to Gunnison River	18	27	6	18	18	18	27	27	3
4 Gunnison River to Loma	18	27	6	18	18	18	27	27	3
5 Loma to Westwater Canyon	9	9	3	9	6	9	6	2	0
6 Westwater Canyon	0	0	0	0	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0	1
13 Green River to Lake Powell	0	0	0	0	0	0	0	0	0
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	14	21	6	18	18	14	24	27	1
15 Gunnison–Roubideau to Colorado	21	21	9	24	18	21	16	6	1
Dolores River	0	0	0	0	0	0	0	0	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each life stage (Tables 21 to 24) were multiplied by life stage weight and weighted scores summed for each reach-habitat combination. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum. Scores for spawning bar complexes are based only on reach use (Table 9).

5.4 ALL SPECIES

Reach-habitat scores for all species and life stages combined are provided in Table 26. These scores are the overall scores for each species (Tables 15, 20, and 25) weighted according to the population status of the species in each subbasin; thus, they reflect differences in priorities among species with higher priority given to species whose low population status. This process places greater emphasis on razorback sucker reach-habitat scores in both subbasins, humpback chub in the Green River subbasin, and Colorado pikeminnow in the upper Colorado River subbasin.

In the Green River, the highest reach-habitat scores were for habitats in the Split Mountain Canyon to Desolation Canyon, Desolation and Gray Canyons, Gray Canyon to Labyrinth Canyon, Labyrinth and Stillwater Canyon reaches. Backwater, side channel, flooded tributary mouth, and flooded bottomland habitats had the highest scores for the Split Mountain Canyon to Desolation Canyon reach, reflecting habitat use by Colorado pikeminnow and razorback sucker. Eddy and spawning habitats had the highest scores in the Desolation and Gray Canyons reach, reflecting habitat use by humpback chub, and spawning by both the Colorado pikeminnow and humpback chub. Flooded bottomland habitat had the highest score in the Gray Canyon to Labyrinth Canyon reach, reflecting habitat use by razorback suckers. In Labyrinth and Stillwater Canyons, backwater habitat had the highest score, reflecting habitat use by Colorado pikeminnow and razorback suckers. Spawning habitat in Yampa Canyon had a high overall score because all species spawn in this reach.

The highest reach-habitat scores in the upper Colorado River subbasin were for spawning habitat in the Gunnison River to Loma reach (Colorado pikeminnow and razorback suckers), and for backwater habitat in the Jackass Canyon to Moab Bridge and Moab Bridge to Green River reaches (Colorado pikeminnow; Table 26). The next highest scores were for backwaters in the Gunnison River to Loma (Colorado pikeminnow and razorback suckers) and Loma to Westwater Canyon (all three species) reaches; flooded tributary mouths in the Palisade to Gunnison River and Gunnison River to Loma reaches (Colorado pikeminnow and razorback suckers); and runs and eddies in the Loma to Westwater Canyon reach (all three species).

Table 26. Reach-Habitat Scores for All Species and Life Stages Combined

	Reach-Habitat Score[a]								
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	6	9	2	6	6	6	9	6	0
3 Lodore Canyon	81	81	54	15	15	81	27	0	0
4 Yampa River to Island Park	210	240	135	56	56	252	80	0	5
5 Island and Rainbow Parks	126	189	58	192	174	126	225	210	0
6 Split Mountain Canyon	219	249	144	59	59	261	83	0	5
7 Split Mt. to Desolation Canyon	238	357	142	468	432	238	501	552	9
8 Desolation and Gray Canyons	288	378	162	96	96	414	126	0	12
9 Gray Canyon to Labyrinth Canyon	168	252	120	396	360	168	396	450	6
10 Labyrinth and Stillwater Canyons	252	252	180	414	360	234	264	102	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	28	42	8	30	30	28	42	24	0
12 Yampa–Yampa Canyon	186	246	108	64	64	270	82	0	13
Little Snake River	10	15	2	12	12	10	15	6	0
Duchesne River	126	189	62	195	186	126	234	249	3
White River	78	117	30	99	90	78	126	99	0
Price River	18	18	6	12	12	12	12	2	0
San Rafael River	126	189	94	291	282	126	306	399	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	54	81	18	54	54	54	81	81	9
2 DeBeque Canyon to Palisade	54	54	18	54	36	54	36	12	0
3 Palisade to Gunnison River	118	177	50	174	150	118	201	153	11
4 Gunnison River to Loma	126	189	58	210	174	126	225	165	15
5 Loma to Westwater Canyon	162	207	72	198	153	207	132	24	9
6 Westwater Canyon	117	162	69	43	43	180	54	0	3
7 Cottonwood Wash to Dewey Bridge	60	90	36	144	108	60	126	72	6
8 Dewey Bridge to Hittle Bottom	90	90	66	186	132	78	96	22	0
9 Hittle Bottom to White Rapid	48	72	32	132	96	48	108	60	4
10 White Rapid to Jackass Canyon	72	72	48	132	96	60	72	16	0
11 Jackass Canyon to Moab Bridge	126	126	90	252	180	108	132	30	0
12 Moab Bridge to Green River	144	144	96	264	192	120	144	32	3
13 Green River to Lake Powell	150	180	108	46	46	192	60	0	2
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	54	81	22	66	66	54	90	93	3
15 Gunnison–Roubideau to Colorado	114	114	51	135	105	102	90	26	7
Dolores River	18	18	6	12	12	12	12	2	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each species (see Tables 15, 20, and 25) were multiplied by species weight and weighted scores summed for each reach-habitat combination. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

6 GEOMORPHOLOGY INFORMATION NEEDS IN PRIORITY REACHES AND HABITATS

Research data and other information available for those reaches and habitats identified as high priority in Section 5 were evaluated to determine remaining information needs and to establish priorities for future geomorphology research. In identifying information needs, we first considered those reaches and habitats that scored high for all species and life stages combined, and then those reaches and habitats that scored high for each species with all life stages combined. Although reach-habitat scores were developed for each species and life stage, we did not identify the research needed to address those priorities. Sufficient information is provided, however, in Sections 4, 5, and 6 and in Appendices B and C to identify research priorities for individual life stages of species if such is desired. Overall reach-habitat scores are the basis for identifying the highest priority research needs in each subbasin because these scores incorporate the needs of all species and life stages.

6.1 RELATIONSHIPS BETWEEN HABITAT CHARACTERISTICS AND GEOMORPHIC PARAMETERS

As described in Section 3, scores were assigned to represent the hypothesized strength of the dependence of important habitat characteristics on hydrology and geomorphology parameters and to help prioritize parameters for study in important reaches and habitats. Those scores are presented in Tables 27, 28, and 29; dependencies with higher scores are considered to have higher priority for study. Additional information on preferred habitat conditions, hypothesized effects on biological attributes of habitats and the river ecosystem, and hypothesized geomorphic processes that affect the characteristics of habitats are presented in Table C.1. The list of hypothesized effects and processes in Table C.1 is not intended to be exhaustive. Rather, the presentation provides a conceptual overview of important hypothesized effects and processes that served as the basis for identifying information needs.

Of the geomorphology parameters considered, habitat characteristics are most dependent on channel morphology and hydraulics (Table 27), which are themselves interrelated. A thorough understanding of how water moves through the system is essential to understanding how habitats are formed and maintained by flow. Channel morphology is largely a function of geological characteristics and the resulting planform, but it affects the distribution, size, and shape of individual mesohabitats. Sediment particle size and availability (the amount of sediment stored in and entering the channel) scored high for some habitat types and characteristics, especially spawning bar complexes and eddies. Both parameters also can affect channel complexity and overall habitat diversity. Sediment dynamics and the balance between sediment inputs and outputs in a reach have important effects on habitat dimension, amount of habitat within a reach, habitat stability, and bed composition.

Of the base-flow parameters considered, more habitat characteristics are strongly dependent on base-flow magnitude and variability than base-flow timing or duration (Table 28).

Table 27. Hypothesized Relative Dependence of Habitat Characteristics on Geomorphology Parameters[a]

Physical Characteristics of Habitats	Channel Morphology	Hydraulics	Sediment Particle Size	Sediment Availability
Pools				
Dimension	3	3	1	3
Amount in reach	3	3	1	1
Connectedness	3	3	1	3
Intra-annual stability	3	3	3	3
Bed composition	3	3	3	3
Runs				
Dimension	3	3	1	3
Amount in reach	3	3	1	1
Shoreline complexity	3	3	3	1
Intra-annual stability	3	3	3	3
Bed composition	3	3	3	3
Riffles/rapids				
Dimension	3	3	2	3
Amount in reach	3	3	3	2
Intra-annual stability	3	3	3	2
Bed composition	3	3	3	3
Connected Backwaters				
Dimension	3	3	2	3
Amount in reach	3	3	2	3
Initial timing of availability	3	3	1	1
Intra-annual stability	3	3	1	3
Inter-annual availability	3	3	3	3
Within-day stability	3	3	1	3
Side Channels				
Dimension	3	3	2	3
Amount in reach	3	3	2	3
Initial timing of availability	3	3	1	1
Intra-annual stability	3	3	1	3
Inter-annual availability	3	3	3	3
Eddies				
Dimension	3	3	2	3
Amount in reach	3	3	2	2
Shoreline complexity	3	3	3	1
Intra-annual stability	3	3	3	2
Inter-annual stability	3	3	3	3
Bed composition	3	3	3	3
Flooded Tributary Mouths				
Dimension	3	3	1	2
Amount in reach	3	3	1	1
Initial timing of availability	3	3	1	1
Intra-annual stability	3	3	1	1
Inter-annual availability	3	3	1	2

Table 27 (Cont.)

Physical Characteristics of Habitats	Channel Morphology	Hydraulics	Sediment Particle Size	Sediment Availability
Flooded Bottomlands				
Dimension	3	3	3	3
Amount in reach	3	3	1	2
Initial timing of availability	3	3	0	0
Intra-annual stability	3	3	1	1
Inter-annual availability	3	3	3	3
Connection to channel	3	3	3	3
Spawning Bar Complexes				
Dimension	3	3	2	2
Amount in reach	3	3	3	3
Initial timing of availability	3	3	1	3
Velocity	3	3	1	2
Intra-annual stability	3	3	2	2
Inter-annual stability	3	3	2	3
Bed composition	3	3	3	3
Total	147	147	95	113

[a] See Table 3 for descriptions of the relationships between geomorphic parameters and habitat characteristics. Scores: 0 = no dependence, 1 = weak dependence, 2 = moderate dependence, 3 = strong dependence.

Base-flow magnitude affects the amount and dimension of in-channel habitat and some flooded bottomland habitat (depression wetlands) during the summer, autumn, and winter (Tables 28 and C.1). Base-flow magnitude also affects transport rates of fine sediments and, therefore, the bed composition (and, secondarily, the productivity) of habitats. Base-flow variability (including inter-annual, intra-annual, and within-day variability) ranks high for many parameters, especially those related to connection and stability of habitats. Base-flow duration and timing affect relatively fewer habitat characteristics.

In general, habitat characteristics are considered more strongly dependent on peak-flow parameters than on base-flow parameters, and of these dependencies, those on peak-flow magnitude, duration, and frequency were strongest (Table 29). Peak-flow magnitude and duration are critically important for the formation and maintenance of habitats because together they affect the amount of scour of accumulated sediments and encroaching vegetation, and the transport of sediments. The frequency of peak flows determines how often the work of peak flows is performed and is an important factor in long-term channel sediment balance and habitat maintenance. Although fewer habitat characteristics are thought to be strongly dependent on peak-flow timing and variability, these two parameters have important effects on the timing of habitat availability and some other habitat characteristics (Table 29).

Once reach-habitat scores were computed and the dependencies of habitat characteristics on hydrology and geomorphology parameters were scored, we considered the availability of studies addressing important parameters in the highest scoring reaches and habitats. Tables 4, 5, and 6 list available geomorphology studies according to reach and topic for the mainstem

Table 28. Hypothesized Relative Dependence of Habitat Characteristics on Base-Flow Parameters[a]

Physical Characteristics of Habitats	Base-Flow Magnitude	Base-Flow Timing	Base-Flow Duration	Base-Flow Variability
Pools				
Dimension	3	0	3	3
Amount in reach	3	0	3	2
Connectedness	3	0	3	3
Intra-annual stability	2	0	3	3
Bed composition	3	1	3	1
Runs				
Dimension	3	0	3	3
Amount in reach	3	0	3	1
Shoreline complexity	3	0	3	1
Intra-annual stability	1	0	3	3
Bed composition	2	1	2	1
Riffles/rapids				
Dimension	3	0	3	3
Amount in reach	2	0	2	2
Intra-annual stability	1	0	3	3
Bed composition	3	1	3	1
Connected Backwaters				
Dimension	3	0	3	3
Amount in reach	3	0	3	3
Initial timing of availability	3	3	0	3
Intra-annual stability	3	1	3	3
Inter-annual availability	2	0	1	3
Within-day stability	3	1	0	3
Side Channels				
Dimension	2	0	3	2
Amount in reach	3	0	3	3
Initial timing of availability	3	3	0	3
Intra-annual stability	3	1	3	3
Inter-annual availability	2	0	1	3
Eddies				
Dimension	3	0	3	3
Amount in reach	1	0	1	1
Shoreline complexity	3	0	1	3
Intra-annual stability	2	1	3	3
Inter-annual stability	1	0	2	3
Bed composition	3	1	3	1
Flooded Tributary Mouths				
Dimension	1	0	0	1
Amount in reach	1	0	0	1
Initial timing of availability	0	3	0	0
Intra-annual stability	0	0	0	0
Inter-annual availability	1	0	0	1

Table 28 (Cont.)

Physical Characteristics of Habitats	Base-Flow Magnitude	Base-Flow Timing	Base-Flow Duration	Base-Flow Variability
Flooded Bottomlands				
Dimension	2	0	2	0
Amount in reach	2	0	2	2
Initial timing of availability	0	0	0	0
Intra-annual stability	2	0	2	3
Inter-annual availability	2	0	2	2
Connection to channel	0	0	0	0
Spawning Bar Complexes				
Dimension	3	3	0	3
Amount in reach	2	3	0	2
Initial timing of availability	1	3	0	1
Velocity	3	3	0	3
Intra-annual stability	1	2	0	3
Inter-annual stability	1	0	2	3
Bed composition	3	2	3	2
Total	103	33	86	103

[a] See Table 3 for descriptions of the relationships between base-flow parameters and habitat characteristics. Scores: 0 = no dependence, 1 = weak dependence, 2 = moderate dependence, 3 = strong dependence.

Green River, Green River tributaries, and upper Colorado River subbasin, respectively. Data on those important relationships in priority reaches and habitats that had not been provided by previous studies were identified as remaining information needs. Information needs for each high-priority reach-habitat combination are identified and discussed for the Green River subbasin and upper Colorado River subbasin in Sections 6.2 and 6.3, respectively. For each subbasin, information needs are further classified as either (1) a primary information need; (2) a secondary information need; or (3) no additional information needed. The rationale for placement in these categories is discussed below.

6.2 INFORMATION NEEDED TO ADDRESS REACH-HABITAT PRIORITIES IN THE GREEN RIVER SUBBASIN

This section identifies information needed to address reach-habitat priorities in the Green River subbasin. Information needed to address overall reach-habitat priorities (combined scores for all species and life stages) is identified and discussed in Section 6.2.1. Information needed to address reach-habitat priorities for individual species is identified in Section 6.2.2.

6.2.1 Overall Reach-Habitat Priorities in the Green River Subbasin

Information needed to address overall reach-habitat priorities on the basis of existing conditions in the Green River subbasin is presented in Table 30. For this subbasin, the highest

Table 29. Hypothesized Relative Dependence of Habitat Characteristics on Peak-Flow Parameters[a]

Physical Characteristics of Habitats	Peak-Flow Magnitude	Peak-Flow Duration	Peak-Flow Frequency	Peak-Flow Timing	Peak-Flow Variability
Pools					
Dimension	3	3	3	1	2
Amount in reach	3	3	3	1	2
Connectedness	3	3	3	1	2
Intra-annual stability	2	2	2	1	1
Bed composition	3	3	3	1	2
Runs					
Dimension	3	3	3	1	2
Amount in reach	2	2	2	1	2
Shoreline complexity	3	3	3	1	2
Intra-annual stability	2	2	2	1	1
Bed composition	3	3	3	1	2
Riffles/Rapids					
Dimension	3	3	3	1	2
Amount in reach	2	2	2	1	2
Intra-annual stability	2	2	2	1	1
Bed composition	3	3	3	1	2
Connected Backwaters					
Dimension	3	3	3	1	3
Amount in reach	3	3	3	1	3
Initial timing of availability	2	2	2	3	1
Intra-annual stability	2	2	2	1	1
Inter-annual availability	3	3	3	2	3
Within-day stability	1	1	1	0	1
Side Channels					
Dimension	3	3	3	1	3
Amount in reach	3	3	3	1	3
Initial timing of availability	2	2	2	3	1
Intra-annual stability	2	2	2	1	1
Inter-annual availability	3	3	3	2	3
Eddies					
Dimension	3	3	3	1	2
Amount in reach	2	2	2	1	2
Shoreline complexity	3	3	3	1	2
Intra-annual stability	2	2	2	1	2
Inter-annual stability	2	2	2	1	2
Bed composition	3	3	3	1	3
Flooded Tributary Mouths					
Dimension	3	2	2	2	1
Amount in reach	3	2	2	1	1
Initial timing of availability	1	1	1	3	1
Intra-annual stability	1	3	1	1	1
Inter-annual availability	1	1	1	3	3

Table 29 (Cont.)

Physical Characteristics of Habitats	Peak-Flow Magnitude	Peak-Flow Duration	Peak-Flow Frequency	Peak-Flow Timing	Peak-Flow Variability
Flooded Bottomlands					
Dimension	3	3	1	2	0
Amount in reach	3	2	1	2	3
Initial timing of availability	3	2	1	3	1
Intra-annual stability	3	2	1	1	2
Inter-annual availability	3	3	3	2	3
Connection to channel	3	3	3	2	1
Spawning Bar Complexes					
Dimension	3	3	3	2	2
Amount in reach	2	2	2	2	2
Initial timing of availability	1	3	1	3	2
Velocity	2	2	2	2	2
Intra-annual stability	1	2	1	1	1
Inter-annual stability	2	2	2	2	2
Bed composition	3	3	3	2	3
Total	120	120	110	72	92

[a] See Table 3 for descriptions of the relationships between peak-flow parameters and habitat characteristics. Scores: 0 = no dependence, 1 = weak dependence, 2 = moderate dependence, 3 = strong dependence.

overall reach-habitat scores for species and life stages combined were in the Split Mountain Canyon to Desolation Canyon reach (Table 26). High-priority habitats were also identified for the Desolation and Gray Canyons, Gray Canyon to Labyrinth Canyon, and Labyrinth and Stillwater Canyon reaches. Habitats with high scores include connected backwaters, side channels, flooded tributary mouths, and flooded bottomlands. All are low-velocity habitats that serve as critical nursery areas for Colorado pikeminnow and razorback suckers. Examination of Table 4 suggests that these habitats, for the most part, have been well studied. Channel morphology, hydraulics, and sediment transport have been studied in the reach. The availability of flooded bottomland habitats at various peak flows and backwaters and side channel habitats at base flows also have been studied.

Nursery habitat availability has been studied in relatively few years, and, thus, existing studies represent limited snapshots of the relationship between flow magnitude and habitat availability and characteristics. While this limitation may not be a concern for flooded bottomlands and flooded tributary mouths, whose availabilities relative to flow magnitude are expected to vary little from year to year, the extremely dynamic nature of backwater and side-channel habitats demands a greater understanding of the geomorphic processes that form and maintain these channel-margin habitats. Because these two habitat types are closely related geomorphically (most side channels become backwater habitats at lower flow), the two habitat types are considered together when discussing information needs.

Rakowski and Schmidt (1999) developed a conceptual model of the role of peak and base flows in the formation and maintenance of backwater habitat in the Split Mountain Canyon to

Table 30. Information Needed to Address Overall Reach-Habitat Priorities Based on Existing Reach Use in the Green River Subbasin

Reach	Habitat Type	Information Needed
I. Primary Information Needs		
Split Mountain Canyon to Desolation Canyon	Connected backwaters and side channels	• Role of peak flow (magnitude, duration, and frequency) and sediment supply on formation and maintenance of habitats • Effects of antecedent conditions (flow and sediment) and base-flow magnitude on habitat availability • Effects of base-flow variability on inter-annual availability, intra-annual stability, and within-day stability
	Flooded bottomlands	• Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects
Desolation and Gray Canyons	Spawning bar complexes	• Effects of peak flow (magnitude, duration, and frequency), base flow (magnitude and duration), and sediment on habitat conditions during the spawning period
Labyrinth and Stillwater Canyons	Connected backwaters and side channels	• Same as connected backwaters and side channels in Split Mountain Canyon to Desolation Canyon reach
II. Secondary Information Needs		
Split Mountain Canyon to Desolation Canyon	Flooded tributary mouths	• Relationship between habitat availability and flow, including determination of threshold flows that result in inundation of habitat • Effects of flow and sediment on erosion and deposition patterns in habitat and effects on habitat characteristics
Desolation and Gray Canyons	Eddies	• Effects of peak flow (magnitude, duration, and frequency), base flow (magnitude and duration), and sediment on deposition and erosion patterns in large shoreline eddies
Yampa River–Yampa Canyon	Spawning bar complexes	• Same as spawning bar complexes in Desolation and Gray Canyons
III. No Additional Information Needed		
Gray Canyon to Labyrinth Canyon	Flooded bottomlands	• No additional information needed because the frequency of inundation is currently very low and the importance of these habitats to endangered fishes is greatly reduced

Desolation Canyon reach; their study, however, was based on a small portion of this reach and their results have not been verified. Their conceptual model is presumably applicable to other sand-bedded portions of the Green River (e.g., Labyrinth and Stillwater Canyons), but such applicability has not been verified. Additional research to verify their conceptual model and more fully understand such interactions, including the effects of antecedent conditions, are needed (Table 30). Of particular importance will be examination of the effects of peak flow (magnitude, duration, and frequency) and sediments on backwater and side-channel habitat formation; the effects of antecedent flow and sediment conditions on habitat characteristics and availability; and the effects of these factors and base-flow magnitude on habitat availability during the summer, autumn, and winter.

Additional determinations of backwater and side-channel habitat availability under a variety of base-flow conditions should be made. Although determinations of habitat surface area using aerial photography or other remote-sensing techniques (e.g., Bell et al. 1998 and Pucherelli 1990a) are useful, these approaches provide little or no information on other habitat dimensions such as depth and volume. Topographic surveys of representative backwaters over a number of years and hydrologic conditions would provide information that could be used to develop three-dimensional models of the relationship of habitat availability to flow. Such models would be useful for resolving many of the information needs identified for connected backwaters and side channels.

Considerable uncertainty exists regarding the effects of base-flow variability (inter-annual, intra-annual, and within-day) on backwater and side-channel habitat availability and conditions, and studies should address these uncertainties (Table 30). Inter-annual availability, intra-annual stability, and within-day stability of backwater and side-channel habitats are all strongly dependent on this parameter. The relationship between year-specific base-flow magnitude and preceding peak-flow magnitude is of particular interest. The only information currently available to address the issue of inter-annual availability is the conceptual model of Rakowski and Schmidt (1999) discussed in the preceding paragraph and observations of Bell et al. (1998). Existing flow recommendations are based on the assumption that backwaters and side channels with limited flow variability (greater intra-annual and within-day stability) provide better habitat conditions. An understanding of these relationships is particularly important for reaches where hydropower operations could influence variability (e.g., the Split Mountain Canyon to Desolation Canyon reach). Studies are underway to evaluate the effects of within-day variability, but results are not yet available.

The relationships between flow and the availability of flooded bottomlands are less dynamic and variable than those for backwaters and side channels, and thus the relationships between habitat availability and flow that have already been determined (e.g., FLO Engineering 1996) are considered sufficient to address this information need for the Split Mountain Canyon to Desolation Canyon reach. However, some uncertainty exists regarding the geomorphic processes that affect connectivity of flooded bottomlands. Of particular importance is determination of the effects that peak flow (magnitude, duration, and frequency) and sediment availability have on sediment erosion and deposition patterns in these habitats. An understanding of these relationships is important for maintaining connection to flooded bottomlands during peak flows and would provide useful information for restoration efforts that are currently underway. It is possible that ongoing active management of large areas of restored flooded bottomland habitats in the Split Mountain Canyon to Desolation Canyon reach, which includes maintenance of high-water connections to the main channel, will lower the priority for research on this topic. The Recovery Program is developing a floodplain-management plan for the Upper Colorado River Basin. Research priorities in flooded bottomland habitats should be reconsidered on the basis of that plan.

Flooded bottomlands also had a high overall score in the Gray Canyon to Labyrinth Canyon reach (Table 26). However, vertical accretion of sediments and subsequent vegetation encroachment have resulted in channel narrowing and the formation of natural levees in this reach (Allred and Schmidt 1999). These levees, together with a reduced occurrence of very high flows, reduce substantially the frequency of inundation of flooded bottomlands, reduce the importance of these habitats for endangered fishes, and, therefore, reduce the priority for research on these habitats in this reach. Restoration activities that reconnect flooded bottomlands in this reach would be needed before a high priority would be placed on geomorphic research.

Flooded tributary mouth habitat in the Split Mountain to Desolation Canyon reach had a high overall score. The underlying geomorphic processes associated with these habitats are less complex than other nursery habitats (particularly backwaters), but threshold flows that inundate flooded tributary mouths and the effects of flow on sediment deposition and erosion patterns in these habitats are not well-known. These are considered secondary information needs. Anecdotal information indicates that flooded tributary mouth habitats are inundated at flows above 100 m^3/s (3,500 cfs) (Muth et al. 2000).

The overall score for eddies in Desolation and Gray Canyons is high because of the importance of this habitat for all life stages of humpback chub and for subadult and adult Colorado pikeminnow. The availability of eddies at various flow levels has been recently studied (Orchard and Schmidt 1999), and the shoreline features that create eddies are generally stable structures and persist from year to year. These facts reduce the need for research on this important habitat. Relatively little is known about the effects of flow on sediment deposition and erosion patterns in eddies and the subsequent effect on habitat conditions such as dimension (depth) and bed composition.

Scores were high for spawning bar complexes in the Desolation and Gray Canyons reach and in the Yampa Canyon reach because several species spawn in those reaches. The only studies of spawning bars conducted in either reach was by Harvey et al. (1993) for a Colorado pikeminnow spawning bar in Yampa Canyon and by Harvey and Mussetter (1994) for a suspected spawning bar in Gray Canyon. Studies are needed of these and any other spawning bars in these reaches to determine the interrelationships among peak flow, base flow, and sediment and their effects on the formation and maintenance of suitable spawning habitats and conditions during the spawning period. Higher priority should be given to research of spawning habitats in Desolation and Gray Canyons in the Green River than for those habitats in Yampa Canyon because of the currently greater degree of regulation of Green River flows and presumably greater alteration of geomorphic processes maintaining spawning habitat in that river.

Consideration of potential reach use by endangered fishes in the Green River subbasin does not alter the priorities identified for species and life stages combined (Table B.19). This reflects the fact that the Green River subbasin currently supports all life stages of all three species.

6.2.2 Species-Specific Reach-Habitat Priorities in the Green River Subbasin

Information needed in the Green River subbasin to address species-specific reach-habitat priorities on the basis of existing conditions is presented in Table 31. Priorities for individual species differ somewhat from the overall priorities presented in Section 6.2.1. They are presented here to facilitate possible future decisions based on species-specific needs.

Reach-habitat priorities for the Colorado pikeminnow include nursery habitats (backwaters, side channels, and flooded tributary mouths) in the Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, and Labyrinth and Stillwater Canyons reach, and spawning habitat in Desolation and Gray Canyons and in Yampa Canyon (Table 15). Relative to the Split Mountain Canyon to Desolation Canyon reach, information on nursery habitats is less well developed for the Gray Canyon to Labyrinth Canyon and Labyrinth and Stillwater Canyon reaches, but the information needs for these latter two reaches are similar to those identified for the former (see Section 6.2.1, Table 30). The conceptual model of backwater formation developed for the Split Mountain Canyon to Desolation Canyon reach (Rakowski and Schmidt 1999) should also be applicable to this reach, but the model needs to be verified here. Information needs for spawning bar complexes in Desolation and Gray Canyons and in Yampa Canyon also are presented in Section 6.2.1 (Table 30). On the basis of information presented in Section 6.2.1, the primary information needs for the Colorado pikeminnow in the Green River subbasin are related to (1) connected backwaters and side channels in the Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, and Labyrinth and Stillwater Canyon reaches, and (2) spawning bar complexes in Desolation and Gray Canyons (Table 31).

Reach-habitat priorities for the humpback chub in the Green River subbasin are limited to run, eddy, and spawning habitat in Desolation and Gray Canyons (Table 20), where the largest existing population in the subbasin occurs. Information needs relative to eddy and spawning habitat in this reach are identified in Section 6.2.1 (Table 30). Very little information is available on humpback chub spawning habitat in Desolation and Gray Canyons or anywhere in the Upper Colorado River Basin. Spawning areas need to be identified and a determination needs to be made of the interrelationships among peak flow, base flow, and sediment transport and their effects on the formation and maintenance of suitable spawning habitats and conditions during the spawning period. Very little information on run habitat and related geomorphic processes is available for any reach. Information is needed on the effects of peak flow (magnitude, duration, and frequency), base flow (magnitude and duration), and sediment on the characteristics of runs, including availability, shoreline complexity, and bed composition. However, because runs, as main channel habitats, presumably are less dynamic than channel-margin habitats and the underlying geomorphic processes apparently are less complex, information on run habitats is considered of secondary importance.

Table 31. Information Needed to Address Species-Specific Reach-Habitat Priorities Based on Existing Reach Use in the Green River Subbasin

Species/Reach	Habitat Type	Information Needed
I. Primary Information Needs		
Colorado Pikeminnow		
Split Mountain Canyon to Desolation Canyon	Connected backwaters and side channels	• See Table 30, Split Mountain Canyon to Desolation Canyon
Desolation and Gray Canyons	Spawning bar complexes	• See Table 30, Desolation and Gray Canyons
Gray Canyon to Labyrinth Canyon	Connected backwaters and side channels	• See Table 30, Split Mountain Canyon to Desolation Canyon
Labyrinth and Stillwater Canyons	Connected backwaters and side channels	• Same as previous
Humpback Chub		
Desolation and Gray Canyons	Spawning bar complexes	• See Table 30, Desolation and Gray Canyons
Razorback Sucker		
Split Mountain Canyon to Desolation Canyon	Spawning bar complexes	• Same as previous
	Flooded bottomlands	• See Table 30, Split Mountain Canyon to Desolation Canyon
II. Secondary Information Needs		
Colorado Pikeminnow		
Split Mountain Canyon to Desolation Canyon	Flooded tributary mouths	• See Table 30, Split Mountain Canyon to Desolation Canyon
Gray Canyon to Labyrinth Canyon	Flooded tributary mouths	• Same as previous
Yampa River–Yampa Canyon	Spawning bar complexes	• See Table 30, Yampa Canyon
Humpback Chub		
Desolation and Gray Canyons	Eddies	• See Table 30, Desolation and Gray Canyons
	Runs	• Effects of peak flow (magnitude, duration, and frequency), base flow (magnitude and duration), and sediment on habitat characteristics
Razorback Sucker		
Split Mountain Canyon to Desolation Canyon	Flooded tributary mouths	• See Table 30, Split Mountain Canyon to Desolation Canyon

Table 31 (Cont.)

Species/Reach	Habitat Type	Information Needed
III. No Additional Information Needed		
Razorback Sucker		
Gray Canyon to Labyrinth Canyon	Flooded bottomlands	• See Table 30, Gray Canyon to Labyrinth Canyon
San Rafael River	Flooded bottomlands	• Same as previous

Reach-habitat priorities identified for the razorback sucker in the Green River subbasin include nursery habitats (flooded tributary mouths and flooded bottomland) and spawning bars in the Split Mountain Canyon to Desolation Canyon reach; flooded bottomlands in the Gray Canyon to Labyrinth Canyon reach; and flooded bottomlands at the mouth of the San Rafael River (Table 25).

Although several studies have examined geomorphic properties of the razorback spawning bar in the Split Mountain Canyon to Desolation Canyon reach, additional study is needed to verify the existing conceptual model for this bar (Wick 1997) and to better understand the effects of peak flow (magnitude, duration, frequency, and timing) and sediment on habitat conditions during the spawning period. The current conceptual model indicates that a complex pattern of sediment deposition and erosion affects the conditions on the spawning bar and that current flow regimes produce poor conditions for eggs and larvae. Understanding the geomorphic processes affecting this spawning habitat is critical.

Information needs related to flooded tributary mouths and flooded bottomlands in these reaches are identified in Section 6.2.1 (Table 30). Additional information is not needed for flooded bottomlands at the mouth of the San Rafael River, because, under current conditions, vertical accretion and vegetation encroachment limits the frequency of flooding of these habitats and their subsequent importance as razorback sucker nursery habitats.

Consideration of potential reach use in the Green River subbasin has relatively little effect on species-specific reach-habitat priorities (Tables B.8, B.13, and B.18). High-priority reach-habitat combinations that are based on potential reach use are the same as those that are based on existing reach use (Table 31).

6.3 INFORMATION NEEDED TO ADDRESS REACH-HABITAT PRIORITIES IN THE UPPER COLORADO RIVER SUBBASIN

This section identifies information needed to address reach-habitat priorities in the upper Colorado River subbasin. Information needed to address overall reach-habitat priorities (combined scores for all species and life stages) is identified and discussed in Section 6.3.1. Information needed to address reach-habitat priorities for each species is identified in Section 6.3.2.

6.3.1 Overall Reach-Habitat Priorities in the Upper Colorado River Subbasin

Information needed to address overall reach-habitat priorities in the upper Colorado River subbasin on the basis of existing levels of reach use is presented in Table 32. High-scoring habitats are located in the Palisade to Gunnison reach (flooded tributary mouths), Gunnison River to Loma reach (backwaters, flooded tributary mouths, and spawning bar complexes), Loma to Westwater Canyon reach (runs, backwaters, and eddies), Jackass Canyon and Moab Bridge reach (backwaters), and Moab Bridge to Green River reach (backwaters) (Table 26).

Basic geomorphic properties and processes (e.g., channel morphology, hydraulics, and sediment transport) and the relationships between habitat availability and flow have been studied in all of these reaches (Table 6). A number of studies have examined the availability of connected backwaters and side channels[3] in the upper Colorado River subbasin at different flows (e.g., Pucherelli et al. 1990b; McAda 1993; Trammell and Chart 1999b), and several studies also have looked at underlying geomorphic processes that affect the formation and characteristics of these habitats in the upper river (Pitlick and Van Steeter 1998; Van Steeter and Pitlick 1998; Pitlick et al. 1999).

The work of Pitlick and Van Steeter focused on the effects of a few high-water years in the 1990s on backwaters and side channels in the river upstream of Westwater Canyon. It is important to study flow-habitat relationships in more years (including years with intermediate peaks) and to determine the role of peak-flow magnitude, duration, frequency, and variability on habitat maintenance. Geomorphic processes affecting backwaters in the lower portions of the upper Colorado River (Jackass Canyon to Moab Bridge and Moab Bridge to Green River reaches) have not been studied, and the processes identified for the gravel-bedded upper river would not apply to this sand-bedded reach. The conceptual model of backwater formation and availability for the Green River (Rakowski and Schmidt 1999) should be applicable to the lower river, but the applicability of that model should be verified. Because the backwaters in the lower, sand-bedded portion of the river are more dynamic and influenced by flow conditions and sediment, research on the geomorphic bases of these habitats is considered higher priority than research on backwaters and side channels in the upper river. Research on these habitats in the upper, gravel-bedded portions of the river is considered a secondary information need.

As for the Green River, additional studies of backwater and side-channel availability at a variety of flows need to be conducted because of the dynamic nature of these channel-margin habitats. Because backwaters and side channels in sand-bedded reaches are so dynamic, uncertainties exist regarding the effects of flow variability on the inter-annual availability, intra-annual stability, and within-day stability of backwater habitats. None of the reaches of interest within the upper Colorado River are affected by hydropower fluctuations, thus research on within-day variability is not needed.

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[3] As stated in Section 6.2.1, backwaters and side channels are considered together here when discussing information needs because these two habitat types are closely related geomorphically (most side channels become backwater habitats at lower flow).

Table 32. Information Needed to Address Overall Reach-Habitat Priorities Based on Existing Reach Use in the Upper Colorado River Subbasin

Reach	Habitat Type	Information Needed
I. Primary Information Needs		
Gunnison River to Loma	Spawning bar complexes	• Location and characteristics of spawning habitats • Effects of peak flow (magnitude, duration, frequency, and timing), base flow (magnitude), and sediment on habitat conditions during the spawning period
Jackass Canyon to Moab Bridge	Connected backwaters and side channels	• Role of peak flow (magnitude, duration, and frequency) and sediment on formation and maintenance of habitats • Effects of antecedent flow and sediment conditions on habitat availability • Habitat availability under a variety of base-flow conditions • Effects of base-flow variability on inter-annual availability and intra-annual stability
Moab Bridge to Green River	Connected backwaters and side channels	• Same as connected backwaters and side channels in Jackass Canyon to Moab Bridge reach
II. Secondary Information Needs		
Palisade to Gunnison River	Flooded tributary mouths	• Relationship between habitat availability and flow, including determination of threshold flows that result in inundation of habitat • Effects of flow and sediment on sediment erosion and deposition patterns in habitat and effect on habitat characteristics
Gunnison River to Loma	Connected backwaters and side channels	• Same as connected backwaters and side channels in Jackass Canyon to Moab Bridge reach
	Flooded tributary mouths	• Same as flooded tributary mouths in Palisade to Gunnison River reach
Loma to Westwater Canyon	Runs	• Effects of peak flow (magnitude, duration, and frequency), base flow (magnitude and duration), and sediment on habitat characteristics • Relationship between habitat availability and base-flow magnitude
	Connected backwaters and side channels	• Same as connected backwaters and side channels in Jackass Canyon to Moab Bridge reach
	Eddies	• Effects of peak flow (magnitude, duration, and frequency), base flow (magnitude and duration), and sediment on deposition and erosion patterns in large shoreline eddies • Relationship between habitat availability and base-flow magnitude

Spawning habitat scored high in the Gunnison River to Loma reach because this reach serves or has served as a spawning area for both Colorado pikeminnow and razorback sucker. Studies of spawning habitat have not been conducted in this or any reach in the upper Colorado River subbasin, because spawning is not apparently concentrated in a few areas as it is in the Green River subbasin. Consequently, there is not a clear understanding of the geomorphic basis of spawning habitat in the upper Colorado River subbasin. Pitlick et al. (1999) and Pitlick and Cress (2000) identified half-bankfull flow as being the flow necessary to initiate movement of the coarse bed sediments (initial motion) and bankfull flow as the flow that mobilized bed material on a widespread basis (significant motion). Flows above these thresholds can be assumed to maintain spawning habitats, but more specific information on spawning habitats and the underlying geomorphic processes that affect habitat formation, availability, and characteristics during the spawning season are critically needed in this subbasin. Future studies should focus on identifying the location of suitable spawning habitats and determining how peak flow, base flow, and sediment interact to affect spawning habitat characteristics. If spawning aggregations and associated habitats cannot be identified, representative potential spawning areas should be carefully selected for study.

Flooded tributary mouths have been not been studied in the Palisade to Gunnison River reach, Gunnison River to Loma reach, or elsewhere in the upper Colorado River subbasin (Table 6). As discussed for the Green River, studies of flooded tributary mouth habitat should focus on determining the relationship between habitat availability and flow, including a determination of the threshold flows that result in inundation of habitat. In addition, the effects of flow and sediment on erosion and deposition patterns and the subsequent effects on the characteristics of flooded tributary mouth habitat should be studied. The underlying geomorphic processes associated with these habitats are less complex than other nursery habitats (particularly backwaters), making information needs for this habitat type a secondary priority.

Scores for run and eddy habitat in the Loma to Westwater Canyon reach were high (Table 26). Food production in run habitat as related to bed characteristics (percentage of fines and embeddedness) was examined by Lamarra (1999) and Osmundson et al. (2002), and their data indicated that productivity of run habitats in this reach were relatively high compared with similar habitats farther downstream. They hypothesized that peak-flow magnitude, sediment inputs, and sediment transport interacted to establish this longitudinal pattern in the river. Studies to address this hypothesis in this reach are warranted, as are studies to examine the interrelationships among flow, sediment, and other characteristics of run habitat (e.g., dimension and shoreline complexity). However, these studies are considered lower priority than others because existing conditions in this reach appear to be suitable for endangered fishes.

Eddies in the Loma to Westwater Canyon reach, or elsewhere in the upper Colorado River subbasin, have not been as well studied as in the Green River. Lamarra (1999) determined the availability of eddies and other habitats in most of the upper Colorado River during the summer base-flow period in 1996. Studies are needed to determine the availability of these habitats in more years and at a wider variety of base-flow levels and to determine the effects of flow and sediment on sediment deposition and erosion patterns in eddies and the resulting habitat conditions. The fact that the shoreline features that create eddies are generally stable structures and persist from year to year reduces the relative importance of information needs for this habitat, and, consequently, information on eddy habitat is considered a secondary priority.

Consideration of potential reach use, as opposed to existing use, in the upper Colorado River subbasin results in important changes in reach-habitat priorities (Table B.19). These changes result from the large differences between patterns of existing reach use and potential use, especially for the razorback sucker. On the basis of potential reach use, high-priority habitats were identified in the following reaches: Rulison to DeBeque Canyon, Palisade to Gunnison River, Gunnison River to Loma, Loma to Westwater Canyon, Moab Bridge to Green River, and in both reaches of the Gunnison River. Habitats with high scores include connected backwaters, side channels, flooded tributary mouths, flooded bottomlands, and spawning bar complexes. Of these, only flooded bottomlands did not also have high scores on the basis of existing reach use, and addition of this habitat reflects its importance as potential nursery habitat for the razorback sucker.

Information needed to address reach-habitat priorities on the basis of potential reach use is presented in Table 33. In general, the reach- and habitat-specific information needs and their priorities that were identified on the basis of existing reach use are applicable to the same habitat types identified on the basis of potential reach use; the reader is referred to information presented in Table 32 and discussed above for further detail.

Determining the availability of flooded bottomland habitat in the Palisade to Gunnison River and Gunnison River to Loma reach is considered to be a top priority for future research. The potential availability of flooded bottomland habitat was identified in all priority reaches by Irving and Burdick (1995); however, the actual relationships between peak-flow magnitude and flooded bottomland inundation in priority reaches has not been examined. Information similar to that developed by FLO Engineering (1996) for the Split Mountain Canyon to Desolation Canyon reach of the Green River would be most useful and is considered a primary information need because of the importance of these habitats for successful razorback sucker recruitment. The relationship between peak-flow magnitude and flooded bottomland area in the Gunnison River (Hartland Dam to Roubideau Creek reach) was determined recently (McAda 2003) and is not considered an information need. Determinations of the availability of flooded bottomlands in the Rulison to DeBeque reach would be useful but are considered to be secondary to other information needs. This reach is upstream of existing barriers to fish passage, and, thus, research could be postponed until after passage is re-established, and populations become established in the upper river.

As discussed in Section 6.2.1, there is some uncertainty regarding the geomorphic processes that affect connectivity of flooded bottomlands to the main channel. Of particular importance is determination of the effects that peak flow (magnitude, duration, and frequency) and sediment availability have on sediment erosion and deposition patterns in these habitats. An understanding of these relationships is important for maintaining connection to flooded bottomlands during peak flows, and would be valuable for current restoration efforts.

Table 33. Information Needed to Address Overall Reach-Habitat Priorities Based on Potential Reach Use in the Upper Colorado River Subbasin

Reach	Habitat Type	Information Needed
I. Primary Information Needs		
Palisade to Gunnison River	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
	Flooded bottomlands	• Habitat availability under a variety of peak- and base-flow conditions • Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects
Gunnison River to Loma	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
	Flooded bottomlands	• Same as flooded bottomlands in Palisade to Gunnison River reach
Loma to Westwater Canyon	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Moab Bridge to Green River	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
Gunnison River—Hartland Dam to Roubideau Creek	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
	Flooded bottomlands	• Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects
Gunnison River—Roubideau Creek to Colorado River	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
II. Secondary Information Needs		
Rulison to DeBeque Canyon	Flooded bottomlands	• Same as flooded bottomlands in Palisade to Gunnison River reach
Palisade to Gunnison River	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River to Loma	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Loma to Westwater Canyon	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
Gunnison River—Hartland Dam to Roubideau Creek	Connected backwaters and side channels	• Same as previous
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach

6.3.2 Species-Specific Reach-Habitat Priorities in the Upper Colorado River Subbasin

Information needed for the upper Colorado River subbasin to address species-specific reach-habitat priorities on the basis of existing conditions is presented in Table 34. Priorities for individual species differ from the overall priorities presented in Section 6.3.1. These priorities are presented here to facilitate possible future decisions based on species-specific needs.

Reach-habitat priorities identified for the Colorado pikeminnow in the upper Colorado River subbasin include spawning habitats in the Gunnison River to Loma, Loma to Westwater Canyon, and Cottonwood Wash to Dewey Bridge reaches; and connected backwaters in the Jackass Canyon to Moab Bridge and Moab Bridge to Green River reaches (Table 15). Information needs for these habitats are discussed in Section 6.3.1.

Priorities for the humpback chub in the upper Colorado River subbasin are identified for the adjacent Loma to Westwater Canyon and Westwater Canyon reaches, where a large population of humpback chub resides (Table 20). Runs, eddies, and spawning habitats in these reaches were the habitats identified as high priority. Primary and secondary information needs for these habitats are discussed in Section 6.3.1.

Consideration of reach-habitat priorities for the razorback sucker increases the number of high-priority reaches and habitats in the upper Colorado River subbasin (Table 25). This increase results at least in part from the existing low occurrence of species in the subbasin. In calculating overall scores, razorback sucker reach-habitat scores are swamped by the higher scores of the Colorado pikeminnow and humpback chub, which are more numerous in the subbasin. Priority reaches for the razorback sucker in the Colorado River include Rulison to DeBeque Canyon, Palisade to Gunnison River, and Gunnison River to Loma. In the Gunnison River, both the Hartland Dam to Roubideau Creek reach and the Roubideau Creek to Colorado River reach are identified as high priority.

Habitats identified as high priority for the razorback sucker in the Colorado River include runs, flooded tributary mouths, flooded bottomlands, and spawning bar complexes; information needs for these habitats and their relative priority are presented in Table 34 and discussed in Section 6.3.1. In the Gunnison River, pools, runs, eddies, flooded tributary mouths, and flooded bottomlands had high scores. Information needs and their relative priority for these habitats also are presented in Table 34 and discussed in Section 6.3.1. Additional information on pools is not considered needed because these habitats have been fairly well studied in the Gunnison River. Flows needed to form and maintain pool habitat in the Gunnison River were studied by Milhous (1998). The availability of pool habitat under different flow conditions were studied by McAda and Fenton (1998).

Consideration of potential reach use of the three species in the upper Colorado River subbasin results in some changes in reach-habitat scores. For the Colorado pikeminnow, nursery habitats (backwaters, side channels, and flooded tributary mouths) in three additional reaches (Palisade to Gunnison River, Gunnison River to Loma, and Cottonwood Wash to Dewey Bridge) and spawning habitats in four additional reaches (DeBeque Canyon to Palisade, Palisade to

Table 34. Information Needed to Address Species-Specific Reach-Habitat Priorities Based on Existing Reach Use in the Upper Colorado River Subbasin

Species/Priority Reach	Priority Habitat	Information Needed
I. Primary Information Needs		
Colorado Pikeminnow		
Gunnison River to Loma	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Loma to Westwater Canyon	Spawning bar complexes	• Same as previous
Cottonwood Wash to Dewey Bridge	Spawning bar complexes	• Same as previous
Jackass Canyon to Moab Bridge	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
Moab Bridge to Green River	Connected backwaters and side channels	• Same as previous
Humpback Chub		
Loma to Westwater Canyon	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Westwater Canyon	Spawning bar complexes	• Same as previous
Razorback Sucker		
Palisade to Gunnison River	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Gunnison River to Loma	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Gunnison River–Hartland to Roubideau	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
II. Secondary Information Needs		
Humpback Chub		
Loma to Westwater Canyon	Runs	• See Table 32, Loma to Westwater Canyon reach
	Eddies	• See Table 32, Loma to Westwater Canyon reach
Westwater Canyon	Runs	• See Table 32, Loma to Westwater Canyon reach
	Eddies	• See Table 32, Loma to Westwater Canyon reach
Razorback Sucker		
Rulison to DeBeque Canyon	Runs	• See Table 32, Loma to Westwater Canyon reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach

Table 34 (Cont.)

Species/Priority Reach	Priority Habitat	Information Needed
II. Secondary Information Needs (Continued)		
Razorback Sucker (Continued)		
Rulison to DeBeque Canyon	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Palisade to Gunnison River	Runs	• See Table 32, Loma to Westwater Canyon reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River to Loma	Runs	• See Table 32, Loma to Westwater Canyon reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River–Hartland to Roubideau	Runs	• See Table 32, Loma to Westwater Canyon reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River–Roubideau to Colorado River	Runs	• See Table 32, Loma to Westwater Canyon reach
	Eddies	• See Table 32, Loma to Westwater Canyon reach
III. No Additional Information Needed		
Razorback Sucker		
Gunnison River–Roubideau to Colorado River	Pools	• Previous studies have identified geomorphic processes affecting habitat in reach and availability of habitat at different flows

Gunnison River, and both reaches of the Gunnison River) had high scores (Tables B.8). Reach-habitat priorities for the humpback chub do not change when potential reach use is considered (Table B.13). Consideration of potential reach use by razorback sucker shifts priorities away from adult habitats to spawning habitats and/or nursery habitats (connected backwaters, flooded tributary mouths, and flooded bottomlands) in five reaches (Rulison to DeBeque Canyon, Palisade to Gunnison River, Gunnison River to Loma, Moab Bridge to Green River, and the Hartland to Roubideau reach of the Gunnison River) (Table B.18). As presented in Table 35, the most important information needs are related to spawning habitats, connected backwaters and side channels in sand-bedded reaches (Cottonwood Wash to Dewey Bridge, Moab Bridge to Green River), and flooded bottomlands. Of secondary importance is information on connected backwaters and side channels in gravel-bedded reaches (Palisade to Gunnison and Gunnison River to Loma), flooded tributary mouths, runs, and eddies.

Table 35. Information Needed to Address Species-Specific Reach-Habitat Priorities Based on Potential Reach Use in the Upper Colorado River Subbasin

Species/Priority Reach	Priority Habitat	Information Needed
I. Primary Information Needs		
Colorado Pikeminnow		
Palisade to Gunnison River	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Gunnison River to Loma	Spawning bar complexes	• Same as previous
Loma to Westwater Canyon	Spawning bar complexes	• Same as previous
Cottonwood Wash to Dewey Bridge	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Moab Bridge to Green River	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
Gunnison River–Hartland to Roubideau	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Gunnison River–Roubideau to Colorado River	Spawning bar complexes	• Same as previous
Humpback Chub		
Loma to Westwater Canyon	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Westwater Canyon	Spawning bar complexes	• Same as previous
Razorback Sucker		
Palisade to Gunnison River	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Gunnison River to Loma	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Moab Bridge to Green River	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Gunnison River–Hartland to Roubideau	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach

Table 35 (Cont.)

Species/Priority Reach	Priority Habitat	Information Needed
II. Secondary Information Needs		
Colorado Pikeminnow		
DeBeque Canyon to Palisade	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Palisade to Gunnison River	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River to Loma	Connected backwaters and side channels	• See Table 32, Jackass Canyon to Moab Bridge reach
	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Cottonwood Wash to Dewey Bridge	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Moab Bridge to Green River	Flooded tributary mouths	• Same as previous
Humpback Chub		
Loma to Westwater Canyon	Runs	• See Table 32, Loma to Westwater Canyon reach
	Eddies	• See Table 32, Loma to Westwater Canyon reach
Westwater Canyon	Runs	• See Table 32, Loma to Westwater Canyon reach
	Eddies	• See Table 32, Loma to Westwater Canyon reach
Razorback Sucker		
Rulison to DeBeque Canyon	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
	Flooded bottomlands	• See Table 33, Palisade to Gunnison reach
	Spawning bar complexes	• See Table 32, Gunnison River to Loma reach
Palisade to Gunnison River	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River to Loma	Flooded tributary mouths	• See Table 32, Palisade to Gunnison River reach
Gunnison River–Hartland to Roubideau	Flooded tributary mouths	• See Table 32, Loma to Westwater Canyon reach

7 RECOMMENDATIONS

The presentation of reach-habitat priorities and associated information needs in Section 6 is intended to provide the Recovery Program with some flexibility as decisions are made on the direction of future geomorphology and habitat research. We present priorities on the basis of existing reach use, potential reach use, overall reach-habitat priorities for all species and life stages combined, and species-specific priorities with life stages combined. We also present sufficient information to allow identification of information needs for life-stage-specific priorities. Values in our linked-matrix spreadsheets can be updated with new information to recalculate priorities, and different weighting schemes can be used to place different emphasis on particular life stages or species.

Because of the uncertainties associated with potential reach use, it would be preferable to focus all research on those primary information needs that are based on existing reach use. The Green River subbasin currently supports populations of Colorado pikeminnow, humpback chub, and razorback sucker, and existing levels of reach use in that subbasin are considered adequate to identify research priorities. However, for several reasons, we believe that priorities in the upper Colorado River subbasin should be based on potential reach use. First, proposed fish passage in the upper river will give endangered razorback suckers and Colorado pikeminnow access to currently unoccupied reaches in the upper river, and research should not ignore these areas. Second, razorback suckers are poorly represented in the subbasin and current stocking programs could substantially change the population status and distribution of that species. Finally, little razorback sucker reproduction has occurred in the subbasin in recent decades, and, therefore, the habitat needs of early life stages are not emphasized in reach-habitat scores based on existing reach use. As the status of populations change in response to management actions, including stocking, habitat improvements, and reconnection to historic habitat, priorities for the upper Colorado River subbasin should be reconsidered.

We recommend a phased, integrated approach to implementation of the research priorities identified in this report. Primary information needs for overall reach-habitat priorities should receive the highest emphasis for research. Research on these topics and reaches has the potential to have the largest benefit to recovery of the endangered fishes. Consideration should also be given to the primary species-specific information needs that we have identified. As would be expected, there is overlap between overall priorities and species-specific priorities. Primary information needs for overall and species-specific reach-habitat priorities in the Green River and upper Colorado River subbasins are outlined below.

I. Primary Information Needs to Address Overall Reach-Habitat Priorities

Green River Subbasin (based on existing conditions in the subbasin)

1. Connected backwaters and side channels (Split Mountain Canyon to Desolation Canyon and Labyrinth and Stillwater Canyons)
    - Role of peak flow (magnitude, duration, and frequency) and sediment on formation and maintenance of habitats

- Effects of antecedent conditions (flow and sediment) and base-flow magnitude on habitat availability
- Effects of base-flow variability on inter-annual availability, intra-annual stability, and within-day stability

2. Flooded bottomlands (Split Mountain Canyon to Desolation Canyon)
   - Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects
3. Spawning bar complexes (Desolation and Gray Canyons)
   - Effects of peak flow (magnitude, duration, frequency, and timing), base flow (magnitude and duration), and sediment on habitat conditions during the spawning period

Upper Colorado River Subbasin (based on potential conditions in the subbasin)

1. Connected backwaters and side channels (Moab Bridge to Green River)
   - Same as those identified for Split Mountain Canyon to Desolation Canyon reach of the Green River
2. Flooded bottomlands (Palisade to Gunnison River and Gunnison River to Loma)
   - The relationship of habitat availability to peak-flow and base-flow magnitude
   - Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects
3. Flooded bottomlands (Gunnison River—Hartland Dam to Roubideau Creek)
   - Effects of peak flow (magnitude, duration, and frequency), sediment, and configuration of connection to main channel on maintenance of connection and sediment deposition effects
4. Spawning bar complexes in the Colorado River (Palisade to Gunnison River, Gunnison River to Loma, and Loma to Westwater) and Gunnison River (Hartland Dam to Roubideau Creek, Roubideau Creek to Colorado River)
   - Location and characteristics of spawning habitats
   - Effects of peak flow (magnitude, duration, frequency, and timing), base flow (magnitude and duration), and sediment on habitat conditions during the spawning period

II. Primary Information Needs to Address Species-Specific Reach-Habitat Priorities

Green River Subbasin (based on existing conditions in the subbasin)

1. Colorado Pikeminnow
    a. Connected backwaters and side channels (Split Mountain Canyon to Desolation Canyon, Gray Canyon to Labyrinth Canyon, Labyrinth and Stillwater Canyons)
        - Same as those identified for Split Mountain Canyon to Desolation Canyon reach under overall reach-habitat priorities above
    b. Spawning bar complexes (Desolation and Gray Canyons)
        - Same as those identified for Desolation and Gray Canyons reach under overall reach-habitat priorities above
2. Humpback Chub
    a. Spawning bar complexes (Desolation and Gray Canyons)
        - Same as those identified for Desolation and Gray Canyons reach under overall reach-habitat priorities above
3. Razorback Sucker
    a. Spawning bar complexes (Split Mountain Canyon to Desolation Canyon)
        - Same as those identified for Desolation and Gray Canyons under overall reach-habitat priorities above
        - Location of additional potential spawning areas in reach
    b. Flooded bottomlands (Split Mountain Canyon to Desolation Canyon)
        - Same as those identified for Split Mountain Canyon to Desolation Canyon reach under overall reach-habitat priorities above

Upper Colorado River Subbasin (based on potential conditions in the subbasin)

1. Colorado Pikeminnow
    a. Connected backwaters and side channels (Cottonwood Wash to Dewey Bridge, Jackass Canyon to Moab Bridge, Moab Bridge to Green River)
        - Same as those identified for connected backwaters in Split Mountain Canyon to Desolation Canyon reach of the Green River under overall reach-habitat priorities above
    b. Spawning bar complexes in the Colorado River (Palisade to Gunnison River, Gunnison River to Loma, Loma to Westwater, Cottonwood Wash to Dewey Bridge) and Gunnison River (Hartland Dam to Roubideau Creek, Roubideau Creek to Colorado River)
        - Same as those identified for spawning bar complexes in upper Colorado River subbasin under overall reach-habitat priorities

2. Humpback Chub
    a. Spawning bar complexes (Loma to Westwater Canyon—Black Rocks portion, Westwater Canyon)
        - Same as those identified for spawning bar complexes in upper Colorado River subbasin under overall reach-habitat priorities
3. Razorback Sucker
    a. Flooded bottomlands (Palisade to Gunnison River, Gunnison River to Loma, Gunnison River—Hartland Dam to Roubideau Creek)
        - Same as those identified for flooded bottomlands in upper Colorado River subbasin under overall reach-habitat priorities above
    b. Spawning bar complexes in the Colorado River (Palisade to Gunnison River, Gunnison River to Loma, Moab Bridge to Green River) and Gunnison River (Hartland Dam to Roubideau Creek)
        - Same as those identified for spawning bar complexes in upper Colorado River subbasin under overall reach-habitat priorities
    c. Connected backwaters and side channels (Moab Bridge to Green River)
        - Same as those identified for connected backwaters in Split Mountain Canyon to Desolation Canyon reach of the Green River under overall reach-habitat priorities above

One aspect of a phased, integrated approach is consideration of the sequence of research projects to address the information needs identified above. For instance, rather than attempting to determine the geomorphic basis of spawning habitats in all eight of the identified high-priority reaches of the upper Colorado River subbasin simultaneously, research should focus on a limited subset of representative spawning areas in one or a few of these reaches. Reaches should be selected for further study on the basis of the results of initial studies to identify and characterize spawning habitats in the subbasin. As relationships among flow, geomorphology, and habitat characteristics are determined in representative study reaches, results can be verified in other high-priority reaches.

All research on geomorphic processes and habitats should be based on hypothesis testing. We recommend planned experimental manipulations and testing of predicted responses whenever possible. Experimental manipulations will be easier to perform in some rivers and reaches than in others, depending on the ability to manipulate flows with existing river regulation structures. Thus, experimental manipulations of flows will be easiest in the middle Green River and in the Gunnison River, but more difficult in the upper Colorado River and any of the tributaries considered in this report.

Although the approach used here prioritizes individual habitats, reaches, and rivers for study in the Upper Colorado River Basin, strong linkages exist among these and they cannot be viewed in isolation. To understand the geomorphic processes important in shaping an individual habitat in a particular reach and river will require a determination of how the habitat functions in context with the entire fluvial system. Similarly, life stages of species cannot be viewed in isolation, and all are obviously necessary to the species' survival. Our approach identifies the reaches and habitats that have the highest priority information needs. To understand these individual reaches and habitats, we need to understand critical relationships to other system components. Researchers should consider these linkages in developing their study approach.

Any research on geomorphic processes and endangered fish habitats will require accurate and continuous information on flow and sediment loads. Collocated sediment-load gages and USGS stream flow gages would provide information needed to develop an understanding of the relationships between habitat characteristics, flow, and sediment load. Re-installation and operation of sediment-load gages at selected mainstem gages is considered a high priority. Information provided by these gages will be applicable to many of the information needs identified in this report and could be used to address many of the uncertainties that have been identified in recent flow recommendation reports (e.g., Muth et al. 2000; McAda 2003).

Research will be conducted by different principal investigators and research staff representing several agencies and organizations. Therefore, adherence to Recovery Program review and approval procedures will be important to ensure that the research conducted adequately addresses information needs. We further recommend standardization of research protocols and data-collection techniques wherever possible. Because of the commonality of information needs among subbasins and reaches, the value of research will depend on the ability to draw conclusions based on cross comparisons. Therefore, the research should be designed and conducted in ways that make such cross comparisons possible and meaningful.

It is important to recognize that this set of recommendations is based on current understanding of habitat requirements and geomorphic processes. It is likely that adjustments to research priorities will be necessary as the research proceeds, and, indeed, the success of the effort will require such adaptation as new information is obtained and inferences are drawn. The research priorities identified in this report are recommendations based on data needs and their importance to recovery. However, ultimately, the Recovery Program will determine the direction of future research, and multiple factors (including, but not limited to those considered in this report) will be considered in those determinations.

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APPENDIX A

WORKSHOP PARTICIPANTS

The following individuals participated in workshops for this project. The workshops were held in Grand Junction, Colorado, on December 11 and 12, 2002, and February 3 and 4, 2003.

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APPENDIX B

REACH AND HABITAT PRIORITIES BASED ON POTENTIAL POPULATION DISTRIBUTIONS

The linked-matrix approach described in Section 3 and applied in the main text for *existing* habitat use was also used to determine reach-habitat priorities on the basis of *potential* habitat use. Once scores were obtained for species and life stages for existing levels of reach use, consideration was given to potential use of reaches by assuming improvements in conditions in response to implementation of flow recommendations, planned removal of existing barriers to passage, and successful establishment of populations through augmentation. Consideration of potential reach use was especially important for the razorback sucker in the upper Colorado River subbasin, because existing levels of use by that species are so low and so few larvae and juveniles exist in the system. Potential reach use scores were developed on the basis of input from researchers from the USFWS and UDWR (Tables B-1 to B-3) after the workshops. Existing reach-use values were replaced with these scores and priority scores were recalculated following the same procedure described in Section 3. Reach-habitat scores that are based on potential use for species and life stages are presented in Tables B.4 through B.19.

Table B.1. Potential Relative Use of Reaches by Life Stages of the Colorado Pikeminnow[a]

River/Reach	Relative Use of Reach by Life Stage[b] Larvae	Juvenile	Subadult	Adult	Spawning
I. Green River Subbasin					
Green River Mainstem					
1 Flaming Gorge to Browns Park	0	0	0	0	0
2 Browns Park	0	0	0	2	0
3 Lodore Canyon	0	0	1	2	0
4 Yampa River to Island Park	3	0	2	3	0
5 Island and Rainbow Parks	3	1	2	3	0
6 Split Mountain Canyon	3	1	2	3	0
7 Split Mountain to Desolation Canyon	3	3	2	3	0
8 Desolation and Gray Canyons	3	2	3	3	3
9 Gray Canyon to Labyrinth Canyon	3	3	3	3	0
10 Labyrinth and Stillwater Canyons	3	3	3	3	0
Green River Tributaries					
11 Yampa River–Above Yampa Canyon	0	0	1	3	0
12 Yampa River–Yampa Canyon	3	1	2	3	3
Little Snake River	0	0	0	1	0
Duchesne River	0	1	2	2	0
White River	0	1	3	3	0
Price River	0	0	1	1	0
San Rafael River	0	1	1	1	0
II. Upper Colorado River Subbasin					
Colorado River Mainstem					
1 Rulison to DeBeque Canyon	1	0	0	1	1
2 DeBeque Canyon to Palisade	2	0	0	3	3
3 Palisade to Gunnison River	3	3	3	3	3
4 Gunnison River to Loma	3	3	3	3	3
5 Loma to Westwater Canyon	3	3	3	3	3
6 Westwater Canyon	3	1	1	1	0
7 Cottonwood Wash to Dewey Bridge	3	3	2	3	3
8 Dewey Bridge to Hittle Bottom	3	2	1	1	0
9 Hittle Bottom to White Rapid	3	2	2	2	2
10 White Rapid to Jackass Canyon	3	2	2	1	0
11 Jackass Canyon to Moab Bridge	3	3	3	1	0
12 Moab Bridge to Green River	3	3	3	1	0
13 Green River to Lake Powell	2	3	2	1	0
Colorado River Tributaries					
14 Gunnison River–Hartland to Roubideau	2	1	3	3	3
15 Gunnison River–Roubideau to Colorado	3	1	3	3	3
Dolores River	0	0	0	2	0

[a] See Section 3 for reach and life-stage definitions.

[b] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

Table B.2. Potential Relative Use of Reaches by Life Stages of the Humpback Chub[a]

River/Reach	Relative Use of Reach by Life Stage[b]				
	Larvae	Juvenile	Subadult	Adult	Spawning
I. Green River Subbasin					
Green River Mainstem					
1 Flaming Gorge to Browns Park	0	0	0	0	0
2 Browns Park	0	0	0	0	0
3 Lodore Canyon	2	2	2	2	2
4 Yampa River to Island Park	1	1	1	1	1
5 Island and Rainbow Parks	0	0	0	0	0
6 Split Mountain Canyon	1	1	1	1	1
7 Split Mt. to Desolation Canyon	0	0	0	1	0
8 Desolation and Gray Canyons	3	3	3	3	3
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0
Green River Tributaries					
11 Yampa River–Above Yampa Canyon	2	2	2	2	2
12 Yampa River–Yampa Canyon	2	2	2	2	2
Little Snake River	0	0	0	1	0
Duchesne River	0	0	0	0	0
White River	0	0	0	0	0
Price River	0	0	0	0	0
San Rafael River	0	0	0	0	0
II. Upper Colorado River Subbasin					
Colorado River Mainstem					
1 Rulison to DeBeque Canyon	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0
5 Loma to Westwater Canyon	3	3	3	3	3
6 Westwater Canyon	3	3	3	3	3
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0
13 Green River to Lake Powell	2	2	2	2	2
Colorado River Tributaries					
14 Gunnison River–Hartland to Roubideau	0	0	0	0	0
15 Gunnison River–Roubideau to Colorado	0	0	0	1	0
Dolores River	0	0	0	0	0

[a] See Section 3 for reach and life-stage definitions.

[b] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

Table B.3. Potential Relative Use of Reaches by Life Stages of the Razorback Sucker[a]

	Relative Use of Reach by Life Stage[b]				
River/Reach	Larvae	Juvenile	Subadult	Adult	Spawning
I. Green River Subbasin					
Green River Mainstem					
1 Flaming Gorge to Browns Park	0	0	0	0	0
2 Browns Park	0	0	0	0	0
3 Lodore Canyon	0	0	1	1	0
4 Yampa River to Island Park	2	0	2	2	1
5 Island and Rainbow Parks	2	0	2	2	0
6 Split Mountain Canyon	2	0	2	2	1
7 Split Mt. to Desolation Canyon	3	3	3	3	3
8 Desolation and Gray Canyons	1	0	2	2	1
9 Gray Canyon to Labyrinth Canyon	3	3	1	1	2
10 Labyrinth and Stillwater Canyons	3	3	1	1	0
Green River Tributaries					
11 Yampa River–Above Yampa Canyon	0	0	0	0	0
12 Yampa River–Yampa Canyon	3	0	1	1	3
Little Snake River	0	0	0	0	0
Duchesne River	1	1	2	2	1
White River	0	0	1	1	0
Price River	0	0	0	0	0
San Rafael River	3	3	1	1	0
II. Upper Colorado River Subbasin					
Colorado River Mainstem					
1 Rulison to DeBeque Canyon	3	3	3	3	3
2 DeBeque Canyon to Palisade	3	1	1	1	0
3 Palisade to Gunnison River	3	3	3	3	3
4 Gunnison River to Loma	3	3	3	3	3
5 Loma to Westwater Canyon	2	2	2	2	1
6 Westwater Canyon	0	1	1	1	0
7 Cottonwood Wash to Dewey Bridge	0	1	1	1	0
8 Dewey Bridge to Hittle Bottom	0	1	1	1	0
9 Hittle Bottom to White Rapid	0	1	2	2	0
10 White Rapid to Jackass Canyon	0	1	1	1	0
11 Jackass Canyon to Moab Bridge	0	1	1	1	0
12 Moab Bridge to Green River	3	3	3	3	3
13 Green River to Lake Powell	0	0	0	1	0
Colorado River Tributaries					
14 Gunnison River–Hartland to Roubideau	3	3	3	3	3
15 Gunnison River–Roubideau to Colorado	2	1	2	2	2
Dolores River	0	0	0	0	0

[a] See Section 3 for reach and life-stage definitions.

[b] 0 = no use, 1 = little use, 2 = moderate use, 3 = high use.

Table B.4. Reach-Habitat Scores for Colorado Pikeminnow Larvae Based on Potential Reach Use

	Reach-Habitat Score[a]							
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	9	9	9	3	3	9	3	0
5 Island and Rainbow Parks	6	9	6	27	18	6	18	9
6 Split Mountain Canyon	9	9	9	3	3	9	3	0
7 Split Mt. to Desolation Canyon	6	9	6	27	18	6	18	9
8 Desolation and Gray Canyons	9	9	9	3	3	9	3	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	27	18	6	18	9
10 Labyrinth and Stillwater Canyons	9	9	9	27	18	9	12	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	9	3	3	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	2	3	2	9	6	2	6	3
2 DeBeque Canyon to Palisade	6	6	6	18	12	6	8	2
3 Palisade to Gunnison River	6	9	6	27	18	6	18	9
4 Gunnison River to Loma	6	9	6	27	18	6	18	9
5 Loma to Westwater Canyon	9	9	9	27	18	9	12	3
6 Westwater Canyon	9	9	9	3	3	9	3	0
7 Cottonwood Wash to Dewey Bridge	6	9	6	27	18	6	18	9
8 Dewey Bridge to Hittle Bottom	9	9	9	27	18	9	12	3
9 Hittle Bottom to White Rapid	6	9	6	27	18	6	18	9
10 White Rapid to Jackass Canyon	9	9	9	27	18	9	12	3
11 Jackass Canyon to Moab Bridge	9	9	9	27	18	9	12	3
12 Moab Bridge to Green River	9	9	9	27	18	9	12	3
13 Green River to Lake Powell	6	6	6	2	2	6	2	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	4	6	4	18	12	4	12	6
15 Gunnison–Roubideau to Colorado	9	9	9	27	18	9	12	3
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.5. Reach-Habitat Scores for Colorado Pikeminnow Juveniles Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	0	0	0	0	0	0	0	0
5 Island and Rainbow Parks	2	3	2	9	6	2	6	3
6 Split Mountain Canyon	3	3	3	1	1	3	1	0
7 Split Mt. to Desolation Canyon	6	9	6	27	18	6	18	9
8 Desolation and Gray Canyons	6	6	6	2	2	6	2	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	27	18	6	18	9
10 Labyrinth and Stillwater Canyons	9	9	9	27	18	9	12	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	3	3	3	1	1	3	1	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	2	3	2	9	6	2	6	3
White River	2	3	2	9	6	2	6	3
Price River	0	0	0	0	0	0	0	0
San Rafael River	2	3	2	9	6	2	6	3
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	6	9	6	27	18	6	18	9
4 Gunnison River to Loma	6	9	6	27	18	6	18	9
5 Loma to Westwater Canyon	9	9	9	27	18	9	12	3
6 Westwater Canyon	3	3	3	1	1	3	1	0
7 Cottonwood Wash to Dewey Bridge	6	9	6	27	18	6	18	9
8 Dewey Bridge to Hittle Bottom	6	6	6	18	12	6	8	2
9 Hittle Bottom to White Rapid	4	6	4	18	12	4	12	6
10 White Rapid to Jackass Canyon	6	6	6	18	12	6	8	2
11 Jackass Canyon to Moab Bridge	9	9	9	27	18	9	12	3
12 Moab Bridge to Green River	9	9	9	27	18	9	12	3
13 Green River to Lake Powell	9	9	9	3	3	9	3	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	2	3	2	9	6	2	6	3
15 Gunnison–Roubideau to Colorado	3	3	3	9	6	3	4	1
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.6. Reach-Habitat Scores for Colorado Pikeminnow Subadults Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	9	9	6	1	1	9	3	0
4 Yampa River to Island Park	18	18	12	2	2	18	6	0
5 Island and Rainbow Parks	12	18	4	12	12	12	18	12
6 Split Mountain Canyon	18	18	12	2	2	18	6	0
7 Split Mt. to Desolation Canyon	12	18	4	12	12	12	18	12
8 Desolation and Gray Canyons	27	27	18	3	3	27	9	0
9 Gray Canyon to Labyrinth Canyon	18	27	6	18	18	18	27	18
10 Labyrinth and Stillwater Canyons	27	27	9	18	18	18	18	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	6	9	2	6	6	6	9	6
12 Yampa–Yampa Canyon	18	18	12	2	2	18	6	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	12	18	4	12	12	12	18	12
White River	18	27	6	18	18	18	27	18
Price River	9	9	3	6	6	6	6	1
San Rafael River	6	9	2	6	6	6	9	6
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	18	27	6	18	18	18	27	18
4 Gunnison River to Loma	18	27	6	18	18	18	27	18
5 Loma to Westwater Canyon	27	27	9	18	18	18	18	3
6 Westwater Canyon	9	9	6	1	1	9	3	0
7 Cottonwood Wash to Dewey Bridge	12	18	4	12	12	12	18	12
8 Dewey Bridge to Hittle Bottom	9	9	3	6	6	6	6	1
9 Hittle Bottom to White Rapid	12	18	4	12	12	12	18	12
10 White Rapid to Jackass Canyon	18	18	6	12	12	12	12	2
11 Jackass Canyon to Moab Bridge	27	27	9	18	18	18	18	3
12 Moab Bridge to Green River	27	27	9	18	18	18	18	3
13 Green River to Lake Powell	18	18	12	2	2	18	6	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	18	27	6	18	18	18	27	18
15 Gunnison–Roubideau to Colorado	27	27	9	18	18	18	18	3
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.7. Reach-Habitat Scores for Colorado Pikeminnow Adults Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	12	18	4	12	12	12	18	12
3 Lodore Canyon	18	18	12	2	2	18	6	0
4 Yampa River to Island Park	27	27	18	3	3	27	9	0
5 Island and Rainbow Parks	18	27	6	18	18	18	27	18
6 Split Mountain Canyon	27	27	18	3	3	27	9	0
7 Split Mt. to Desolation Canyon	18	27	6	18	18	18	27	18
8 Desolation and Gray Canyons	27	27	18	3	3	27	9	0
9 Gray Canyon to Labyrinth Canyon	18	27	6	18	18	18	27	18
10 Labyrinth and Stillwater Canyons	27	27	9	18	18	18	18	3
Green River Tributaries								
11 Yampa–Above Yampa Canyon	18	27	6	18	18	18	27	18
12 Yampa–Yampa Canyon	27	27	18	3	3	27	9	0
Little Snake River	6	9	2	6	6	6	9	6
Duchesne River	12	18	4	12	12	12	18	12
White River	18	27	6	18	18	18	27	18
Price River	9	9	3	6	6	6	6	1
San Rafael River	6	9	2	6	6	6	9	6
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	6	9	2	6	6	6	9	6
2 DeBeque Canyon to Palisade	27	27	9	18	18	18	18	3
3 Palisade to Gunnison River	18	27	6	18	18	18	27	18
4 Gunnison River to Loma	18	27	6	18	18	18	27	18
5 Loma to Westwater Canyon	27	27	9	18	18	18	18	3
6 Westwater Canyon	9	9	6	1	1	9	3	0
7 Cottonwood Wash to Dewey Bridge	18	27	6	18	18	18	27	18
8 Dewey Bridge to Hittle Bottom	9	9	3	6	6	6	6	1
9 Hittle Bottom to White Rapid	12	18	4	12	12	12	18	12
10 White Rapid to Jackass Canyon	9	9	3	6	6	6	6	1
11 Jackass Canyon to Moab Bridge	9	9	3	6	6	6	6	1
12 Moab Bridge to Green River	9	9	3	6	6	6	6	1
13 Green River to Lake Powell	9	9	6	1	1	9	3	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	18	27	6	18	18	18	27	18
15 Gunnison–Roubideau to Colorado	27	27	9	18	18	18	18	3
Dolores River	18	18	6	12	12	12	12	2

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.8. Reach-Habitat Scores for All Colorado Pikeminnow Life Stages Combined Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]								
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	12	18	4	12	12	12	18	12	0
3 Lodore Canyon	27	27	18	3	3	27	9	0	0
4 Yampa River to Island Park	54	54	39	8	8	54	18	0	0
5 Island and Rainbow Parks	42	63	22	84	66	42	81	48	0
6 Split Mountain Canyon	63	63	48	11	11	63	21	0	0
7 Split Mt. to Desolation Canyon	54	81	34	138	102	54	117	66	0
8 Desolation and Gray Canyons	81	81	63	15	15	81	27	0	3
9 Gray Canyon to Labyrinth Canyon	60	90	36	144	108	60	126	72	0
10 Labyrinth and Stillwater Canyons	90	90	54	144	108	72	84	18	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	24	36	8	24	24	24	36	24	0
12 Yampa–Yampa Canyon	63	63	48	11	11	63	21	0	3
Little Snake River	6	9	2	6	6	6	9	6	0
Duchesne River	30	45	14	51	42	30	54	33	0
White River	42	63	18	63	54	42	72	45	0
Price River	18	18	6	12	12	12	12	2	0
San Rafael River	18	27	10	39	30	18	36	21	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	8	12	4	15	12	8	15	9	1
2 DeBeque Canyon to Palisade	33	33	15	36	30	24	26	5	3
3 Palisade to Gunnison River	60	90	36	144	108	60	126	72	3
4 Gunnison River to Loma	60	90	36	144	108	60	126	72	3
5 Loma to Westwater Canyon	90	90	54	144	108	72	84	18	3
6 Westwater Canyon	36	36	30	8	8	36	12	0	0
7 Cottonwood Wash to Dewey Bridge	54	81	34	138	102	54	117	66	3
8 Dewey Bridge to Hittle Bottom	45	45	33	93	66	39	48	11	0
9 Hittle Bottom to White Rapid	42	63	26	105	78	42	90	51	2
10 White Rapid to Jackass Canyon	54	54	36	99	72	45	54	12	0
11 Jackass Canyon to Moab Bridge	72	72	48	132	96	60	72	16	0
12 Moab Bridge to Green River	72	72	48	132	96	60	72	16	0
13 Green River to Lake Powell	60	60	51	14	14	60	20	0	0
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	46	69	22	81	66	46	84	51	3
15 Gunnison–Roubideau to Colorado	72	72	36	90	72	54	60	12	3
Dolores River	18	18	6	12	12	12	12	2	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each life stage (Tables B.4 to B.7) were multiplied by life stage weight and weighted scores summed for each reach-habitat combination. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum. Scores for spawning bar complexes based only on reach use (Table B.1).

Table B.9. Reach-Habitat Scores for Humpback Chub Larvae Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	6	6	6	4	4	12	4	0
4 Yampa River to Island Park	3	3	3	2	2	6	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	3	3	3	2	2	6	2	0
7 Split Mt. to Desolation Canyon	0	0	0	0	0	0	0	0
8 Desolation and Gray Canyons	9	9	9	6	6	18	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	4	6	4	6	6	4	6	0
12 Yampa–Yampa Canyon	6	6	6	4	4	12	4	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	9	9	9	6	6	18	6	0
6 Westwater Canyon	9	9	9	6	6	18	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	6	6	6	4	4	12	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.10. Reach-Habitat Scores for Humpback Chub Juveniles Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	18	0	4	4	12	4	0
4 Yampa River to Island Park	0	9	0	2	2	6	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	0	9	0	2	2	6	2	0
7 Split Mt. to Desolation Canyon	0	0	0	0	0	0	0	0
8 Desolation and Gray Canyons	0	27	0	6	6	18	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	6	0	6	6	4	6	0
12 Yampa–Yampa Canyon	0	18	0	4	4	12	4	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	0	27	0	6	6	18	6	0
6 Westwater Canyon	0	27	0	6	6	18	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	0	18	0	4	4	12	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.11. Reach-Habitat Scores for Humpback Chub Subadults Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	12	12	0	4	4	18	4	0
4 Yampa River to Island Park	6	6	0	2	2	9	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	6	6	0	2	2	9	2	0
7 Split Mt. to Desolation Canyon	0	0	0	0	0	0	0	0
8 Desolation and Gray Canyons	18	18	0	6	6	27	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	4	6	0	6	6	4	6	0
12 Yampa–Yampa Canyon	12	12	0	4	4	18	4	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	18	18	0	6	6	27	6	0
6 Westwater Canyon	18	18	0	6	6	27	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	12	12	0	4	4	18	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	0	0	0	0	0	0	0	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.12. Reach-Habitat Scores for Humpback Chub Adults Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	12	6	0	2	2	18	4	0
4 Yampa River to Island Park	6	3	0	1	1	9	2	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	6	3	0	1	1	9	2	0
7 Split Mt. to Desolation Canyon	2	3	0	3	3	2	3	0
8 Desolation and Gray Canyons	18	9	0	3	3	27	6	0
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0
Green River Tributaries								
11 Yampa–Above Yampa Canyon	4	6	0	6	6	4	6	0
12 Yampa–Yampa Canyon	12	6	0	2	2	18	4	0
Little Snake River	2	3	0	3	3	2	3	0
Duchesne River	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	18	9	0	3	3	27	6	0
6 Westwater Canyon	18	9	0	3	3	27	6	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	12	6	0	2	2	18	4	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	3	3	0	3	3	3	2	0
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.13. Reach-Habitat Scores for All Humpback Chub Life Stages Combined Based on Potential Reach Use

	Reach-Habitat Score[a]								
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0	0
3 Lodore Canyon	30	60	6	18	18	72	20	0	2
4 Yampa River to Island Park	15	30	3	9	9	36	10	0	1
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	15	30	3	9	9	36	10	0	1
7 Split Mt. to Desolation Canyon	2	3	0	3	3	2	3	0	0
8 Desolation and Gray Canyons	45	90	9	27	27	108	30	0	3
9 Gray Canyon to Labyrinth Canyon	0	0	0	0	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0	0	0	0	0	0	0	0	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	12	30	4	30	30	20	30	0	2
12 Yampa–Yampa Canyon	30	60	6	18	18	72	20	0	2
Little Snake River	2	3	0	3	3	2	3	0	0
Duchesne River	0	0	0	0	0	0	0	0	0
White River	0	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0	0
San Rafael River	0	0	0	0	0	0	0	0	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	0	0	0	0	0	0	0	0	0
2 DeBeque Canyon to Palisade	0	0	0	0	0	0	0	0	0
3 Palisade to Gunnison River	0	0	0	0	0	0	0	0	0
4 Gunnison River to Loma	0	0	0	0	0	0	0	0	0
5 Loma to Westwater Canyon	45	90	9	27	27	108	30	0	3
6 Westwater Canyon	45	90	9	27	27	108	30	0	3
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	0	0	0	0	0	0	0	0	0
13 Green River to Lake Powell	30	60	6	18	18	72	20	0	2
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	0	0	0	0	0	0	0	0	0
15 Gunnison–Roubideau to Colorado	3	3	0	3	3	3	2	0	0
Dolores River	0	0	0	0	0	0	0	0	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each life stage (Tables B.9 to B.12) were multiplied by life stage weight and weighted scores summed for each reach-habitat combination. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum. Scores for spawning bar complexes based only on reach use (Table B.2).

Table B.14. Reach-Habitat Scores for Razorback Sucker Larvae Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	6	6	6	2	2	6	2	0
5 Island and Rainbow Parks	4	6	4	12	12	4	12	18
6 Split Mountain Canyon	6	6	6	2	2	6	2	0
7 Split Mt. to Desolation Canyon	6	9	6	18	18	6	18	27
8 Desolation and Gray Canyons	3	3	3	1	1	3	1	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	18	18	6	18	27
10 Labyrinth and Stillwater Canyons	9	9	9	18	18	9	12	6
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	9	3	3	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	2	3	2	6	6	2	6	9
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	6	18	18	6	18	27
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	6	9	6	18	18	6	18	27
2 DeBeque Canyon to Palisade	9	9	9	18	18	9	12	6
3 Palisade to Gunnison River	6	9	6	18	18	6	18	27
4 Gunnison River to Loma	6	9	6	18	18	6	18	27
5 Loma to Westwater Canyon	6	6	6	12	12	6	8	4
6 Westwater Canyon	0	0	0	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	0	0	0	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	0	0	0	0	0	0	0	0
9 Hittle Bottom to White Rapid	0	0	0	0	0	0	0	0
10 White Rapid to Jackass Canyon	0	0	0	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	0	0	0	0	0	0	0	0
12 Moab Bridge to Green River	9	9	9	18	18	9	12	6
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	6	9	6	18	18	6	18	27
15 Gunnison–Roubideau to Colorado	6	6	6	12	12	6	8	4
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.15. Reach-Habitat Scores for Razorback Sucker Juveniles Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	0	0	0	0	0	0	0	0
4 Yampa River to Island Park	0	0	0	0	0	0	0	0
5 Island and Rainbow Parks	0	0	0	0	0	0	0	0
6 Split Mountain Canyon	0	0	0	0	0	0	0	0
7 Split Mt. to Desolation Canyon	6	9	6	18	18	6	18	27
8 Desolation and Gray Canyons	0	0	0	0	0	0	0	0
9 Gray Canyon to Labyrinth Canyon	6	9	6	18	18	6	18	27
10 Labyrinth and Stillwater Canyons	9	9	9	18	18	9	12	6
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	0	0	0	0	0	0	0	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	2	3	2	6	6	2	6	9
White River	0	0	0	0	0	0	0	0
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	6	18	18	6	18	27
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	6	9	6	18	18	6	18	27
2 DeBeque Canyon to Palisade	3	3	3	6	6	3	4	2
3 Palisade to Gunnison River	6	9	6	18	18	6	18	27
4 Gunnison River to Loma	6	9	6	18	18	6	18	27
5 Loma to Westwater Canyon	6	6	6	12	12	6	8	4
6 Westwater Canyon	3	3	3	1	1	3	1	0
7 Cottonwood Wash to Dewey Bridge	2	3	2	6	6	2	6	9
8 Dewey Bridge to Hittle Bottom	3	3	3	6	6	3	4	2
9 Hittle Bottom to White Rapid	2	3	2	6	6	2	6	9
10 White Rapid to Jackass Canyon	3	3	3	6	6	3	4	2
11 Jackass Canyon to Moab Bridge	3	3	3	6	6	3	4	2
12 Moab Bridge to Green River	9	9	9	18	18	9	12	6
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	6	9	6	18	18	6	18	27
15 Gunnison–Roubideau to Colorado	3	3	3	6	6	3	4	2
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.16. Reach-Habitat Scores for Razorback Sucker Subadults Based on Potential Reach Use

	Reach-Habitat Score[a]							
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	9	9	6	2	2	9	3	0
4 Yampa River to Island Park	18	18	12	4	4	18	6	0
5 Island and Rainbow Parks	12	18	4	12	12	12	18	18
6 Split Mountain Canyon	18	18	12	4	4	18	6	0
7 Split Mt. to Desolation Canyon	18	27	6	18	18	18	27	27
8 Desolation and Gray Canyons	18	18	12	4	4	18	6	0
9 Gray Canyon to Labyrinth Canyon	6	9	2	6	6	6	9	9
10 Labyrinth and Stillwater Canyons	9	9	3	9	6	9	6	2
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	6	2	2	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	12	18	4	12	12	12	18	18
White River	6	9	2	6	6	6	9	9
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	2	6	6	6	9	9
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	18	27	6	18	18	18	27	27
2 DeBeque Canyon to Palisade	9	9	3	9	6	9	6	2
3 Palisade to Gunnison River	18	27	6	18	18	18	27	27
4 Gunnison River to Loma	18	27	6	18	18	18	27	27
5 Loma to Westwater Canyon	18	18	6	18	12	18	12	4
6 Westwater Canyon	9	9	6	2	2	9	3	0
7 Cottonwood Wash to Dewey Bridge	6	9	2	6	6	6	9	9
8 Dewey Bridge to Hittle Bottom	9	9	3	9	6	9	6	2
9 Hittle Bottom to White Rapid	12	18	4	12	12	12	18	18
10 White Rapid to Jackass Canyon	9	9	3	9	6	9	6	2
11 Jackass Canyon to Moab Bridge	9	9	3	9	6	9	6	2
12 Moab Bridge to Green River	27	27	9	27	18	27	18	6
13 Green River to Lake Powell	0	0	0	0	0	0	0	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	18	27	6	18	18	18	27	27
15 Gunnison–Roubideau to Colorado	18	18	6	18	12	18	12	4
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.17. Reach-Habitat Scores for Razorback Sucker Adults Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]							
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB
I. Green River Subbasin								
Green River Mainstem								
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0
3 Lodore Canyon	9	9	6	2	2	9	3	0
4 Yampa River to Island Park	18	18	12	4	4	18	6	0
5 Island and Rainbow Parks	12	18	4	12	12	12	18	18
6 Split Mountain Canyon	18	18	12	4	4	18	6	0
7 Split Mt. to Desolation Canyon	18	27	6	18	18	18	27	27
8 Desolation and Gray Canyons	18	18	12	4	4	18	6	0
9 Gray Canyon to Labyrinth Canyon	6	9	2	6	6	6	9	9
10 Labyrinth and Stillwater Canyons	9	9	3	9	6	9	6	2
Green River Tributaries								
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	9	9	6	2	2	9	3	0
Little Snake River	0	0	0	0	0	0	0	0
Duchesne River	12	18	4	12	12	12	18	18
White River	6	9	2	6	6	6	9	9
Price River	0	0	0	0	0	0	0	0
San Rafael River	6	9	2	6	6	6	9	9
II. Upper Colorado River Subbasin								
Colorado River Mainstem								
1 Rulison to DeBeque Canyon	18	27	6	18	18	18	27	27
2 DeBeque Canyon to Palisade	9	9	3	9	6	9	6	2
3 Palisade to Gunnison River	18	27	6	18	18	18	27	27
4 Gunnison River to Loma	18	27	6	18	18	18	27	27
5 Loma to Westwater Canyon	18	18	6	18	12	18	12	4
6 Westwater Canyon	9	9	6	2	2	9	3	0
7 Cottonwood Wash to Dewey Bridge	6	9	2	6	6	6	9	9
8 Dewey Bridge to Hittle Bottom	9	9	3	9	6	9	6	2
9 Hittle Bottom to White Rapid	12	18	4	12	12	12	18	18
10 White Rapid to Jackass Canyon	9	9	3	9	6	9	6	2
11 Jackass Canyon to Moab Bridge	9	9	3	9	6	9	6	2
12 Moab Bridge to Green River	27	27	9	27	18	27	18	6
13 Green River to Lake Powell	9	9	6	2	2	9	3	0
Colorado River Tributaries								
14 Gunnison–Hartland to Roubideau	18	27	6	18	18	18	27	27
15 Gunnison–Roubideau to Colorado	18	18	6	18	12	18	12	4
Dolores River	0	0	0	0	0	0	0	0

[a] Reach-habitat score = reach use by life stage × habitat use by life stage × habitat occurrence. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

Table B.18. Reach-Habitat Scores for All Razorback Sucker Life Stages Combined Based on Potential Reach Use

	Reach-Habitat Score[a]								
River/Reach	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	0	0	0	0	0	0	0	0	0
3 Lodore Canyon	18	18	12	4	4	18	6	0	0
4 Yampa River to Island Park	42	42	30	10	10	42	14	0	1
5 Island and Rainbow Parks	28	42	12	36	36	28	48	54	0
6 Split Mountain Canyon	42	42	30	10	10	42	14	0	1
7 Split Mt. to Desolation Canyon	60	90	36	108	108	60	126	162	3
8 Desolation and Gray Canyons	39	39	27	9	9	39	13	0	1
9 Gray Canyon to Labyrinth Canyon	36	54	28	84	84	36	90	126	2
10 Labyrinth and Stillwater Canyons	54	54	42	90	84	54	60	28	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	0	0	0	0	0	0	0	0	0
12 Yampa–Yampa Canyon	27	27	21	7	7	27	9	0	3
Little Snake River	0	0	0	0	0	0	0	0	0
Duchesne River	32	48	16	48	48	32	60	72	1
White River	12	18	4	12	12	12	18	18	0
Price River	0	0	0	0	0	0	0	0	0
San Rafael River	36	54	28	84	84	36	90	126	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	60	90	36	108	108	60	126	162	3
2 DeBeque Canyon to Palisade	36	36	24	54	48	36	36	16	0
3 Palisade to Gunnison River	60	90	36	108	108	60	126	162	3
4 Gunnison River to Loma	60	90	36	108	108	60	126	162	3
5 Loma to Westwater Canyon	60	60	36	84	72	60	56	24	1
6 Westwater Canyon	27	27	21	7	7	27	9	0	0
7 Cottonwood Wash to Dewey Bridge	18	27	10	30	30	18	36	45	0
8 Dewey Bridge to Hittle Bottom	27	27	15	36	30	27	24	10	0
9 Hittle Bottom to White Rapid	30	45	14	42	42	30	54	63	0
10 White Rapid to Jackass Canyon	27	27	15	36	30	27	24	10	0
11 Jackass Canyon to Moab Bridge	27	27	15	36	30	27	24	10	0
12 Moab Bridge to Green River	90	90	54	126	108	90	84	36	3
13 Green River to Lake Powell	9	9	6	2	2	9	3	0	0
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	60	90	36	108	108	60	126	162	3
15 Gunnison–Roubideau to Colorado	51	51	27	66	54	51	44	18	2
Dolores River	0	0	0	0	0	0	0	0	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each life stage (Tables B.14 to B.17) were multiplied by life stage weight and weighted scores summed for each reach-habitat combination. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum. Scores for spawning bar complexes are based only on reach use (Table B.3).

Table B.19. Reach-Habitat Scores for All Species and Life Stages Combined Based on Potential Reach Use

River/Reach	Reach-Habitat Score[a]								
	Pool	Run	Riffle	BW	SC	Eddy	FTM	FB	SBC
I. Green River Subbasin									
Green River Mainstem									
1 Flaming Gorge to Browns Park	0	0	0	0	0	0	0	0	0
2 Browns Park	12	18	4	12	12	12	18	12	0
3 Lodore Canyon	141	201	66	51	51	225	67	0	4
4 Yampa River to Island Park	210	240	135	56	56	252	80	0	5
5 Island and Rainbow Parks	126	189	58	192	174	126	225	210	0
6 Split Mountain Canyon	219	249	144	59	59	261	83	0	5
7 Split Mt. to Desolation Canyon	238	357	142	468	432	238	501	552	9
8 Desolation and Gray Canyons	288	378	162	96	96	414	126	0	12
9 Gray Canyon to Labyrinth Canyon	168	252	120	396	360	168	396	450	6
10 Labyrinth and Stillwater Canyons	252	252	180	414	360	234	264	102	0
Green River Tributaries									
11 Yampa–Above Yampa Canyon	48	96	16	84	84	64	96	24	4
12 Yampa–Yampa Canyon	204	264	123	68	68	288	88	0	16
Little Snake River	10	15	2	12	12	10	15	6	0
Duchesne River	126	189	62	195	186	126	234	249	3
White River	78	117	30	99	90	78	126	99	0
Price River	18	18	6	12	12	12	12	2	0
San Rafael River	126	189	94	291	282	126	306	399	0
II. Upper Colorado River Subbasin									
Colorado River Mainstem									
1 Rulison to DeBeque Canyon	196	294	116	354	348	196	408	504	11
2 DeBeque Canyon to Palisade	174	174	102	234	204	156	160	58	6
3 Palisade to Gunnison River	300	450	180	612	540	300	630	630	15
4 Gunnison River to Loma	300	450	180	612	540	300	630	630	15
5 Loma to Westwater Canyon	405	450	225	567	459	432	366	108	12
6 Westwater Canyon	198	243	132	64	64	261	81	0	3
7 Cottonwood Wash to Dewey Bridge	162	243	98	366	294	162	342	267	6
8 Dewey Bridge to Hittle Bottom	171	171	111	294	222	159	168	52	0
9 Hittle Bottom to White Rapid	174	261	94	336	282	174	342	291	4
10 White Rapid to Jackass Canyon	189	189	117	306	234	171	180	54	0
11 Jackass Canyon to Moab Bridge	225	225	141	372	282	201	216	62	0
12 Moab Bridge to Green River	414	414	258	642	516	390	396	140	9
13 Green River to Lake Powell	177	207	126	52	52	219	69	0	2
Colorado River Tributaries									
14 Gunnison–Hartland to Roubideau	272	408	152	486	456	272	546	588	15
15 Gunnison–Roubideau to Colorado	300	300	153	381	309	264	254	78	12
Dolores River	36	36	12	24	24	24	24	4	0

[a] To determine overall reach-habitat scores, reach-habitat scores for each species (see Tables B.8, B.13, and B.18) were multiplied by species weight and weighted scores summed for each reach-habitat combination. See Section 3 for description of scoring methodology and habitat types. BW = backwater, SC = side channel, FTM = flooded tributary mouth, FB = flooded bottomland, SBC = spawning bar complex. Scores are color-coded as follows: red is ≥75% of maximum for subbasin; orange is 50%–75% of maximum, yellow is 25%–50% of maximum.

APPENDIX C

RELATIONSHIPS BETWEEN HABITAT CHARACTERISTICS AND GEOMORPHIC PARAMETERS

Preferred habitat conditions, hypothesized effects on biological attributes of habitats and the river ecosystem, and hypothesized geomorphic processes that affect habitat characteristics are presented in Table C.1. The list of hypothesized effects and processes in Table C.1 is not intended to be exhaustive. Rather, the presentation provides a conceptual overview of important hypothesized effects and processes that served as the basis for identifying information needs discussed in Section 6.

Table C.1. Preferred Condition of Endangered Fish Habitats, Hypothesized Effects of Condition on Biological System and Endangered Fish, and Geomorphic Processes That Affect Habitat Characteristics

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Pools				
Dimension	Moderate to large surface area and depth	Higher within-habitat food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of subadults and adults; higher reproductive rate	Peak flows scour and enlarge pools and remove encroaching vegetation; base-flow magnitude determines volume of individual pools in summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to support recovered adult population	Higher food production in system; greater availability of habitat; greater carrying capacity	Same as previous	Peak flows scour, deepen, and create pools and remove encroaching vegetation; base-flow magnitude determines amount of habitat available in reach; amount and characteristics of sediment affect erosion and aggradation rates of channel
Connectedness	Connection throughout base-flow period	Higher within-habitat food production; longer period of availability of habitat; greater carrying capacity	Same as previous	Peak flows establish and maintain connection with other main-channel habitats, remove encroaching vegetation that might restrict connectivity; sufficient base-flow magnitude maintains connection during summer, autumn, and winter; base-flow variability affects consistency of connection; amount and characteristics of sediment affect erosion and aggradation rates of channel
Intra-annual stability	Relatively stable throughout base-flow period	Higher within-habitat food production; greater carrying capacity	Same as previous	Peak flows scour and enlarge pools, which are more stable, and remove encroaching vegetation that might otherwise trap sediment and reduce pool size; connectivity increases stability; sufficient base-flow magnitude maintains connection during summer, autumn, and winter; base-flow variability reduces stability of habitat; amount and characteristics of sediment affect erosion and aggradation rates of channel
Bed composition	Low percentage of fine sediment, low embeddedness	Same as previous	Same as previous	Peak flows mobilize bed material and reduce embeddedness; base flows winnow fine material from other habitats and deposit in pools; fine sediments reduce primary production of attached submergent macrophytes and reduce production of benthic invertebrates; amount and characteristics of sediment affect erosion and aggradation rates of bed

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Runs				
Dimension	Moderate to large surface area, moderate depth	Higher within-habitat food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of subadults and adults; higher reproductive rate	Peak flows scour, remove encroaching vegetation; base-flow magnitude determines volume of individual runs; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to support recovered adult population	Higher food production in system; greater availability of habitat; greater carrying capacity	Same as previous	Peak flows scour, deepen, and create runs, remove encroaching vegetation; base-flow magnitude determines amount of habitat in reach; amount and characteristics of sediment affect erosion and aggradation rates of channel
Shoreline complexity	High to moderate levels of complexity	Greater microhabitat diversity and velocity shelters; greater carrying capacity	Same as previous	Shoreline complexity affected by sediment particle size and channel morphology; peak flows mobilize and transport sediment and can affect complexity
Intra-annual stability	Relatively stable throughout base-flow period	Higher within-habitat food production; greater carrying capacity	Same as previous	Peak flows scour and enlarge runs (larger runs are more stable) and remove encroaching vegetation that might otherwise trap sediment and reduce run size; sufficient base-flow magnitude maintains habitat area during summer, autumn, and winter; base-flow variability reduces stability of habitat; amount and characteristics of sediment affect erosion and aggradation rates of channel
Bed composition	Low percentage of fine sediment, low embeddedness	Same as previous	Same as previous	Peak flows mobilize bed material and reduce embeddedness; base flows winnow fine material from bed; fine sediments reduce primary production of submergent macrophytes and reduce production of benthic invertebrates; amount and characteristics of sediment affect erosion and aggradation rates of bed

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Riffles/Rapids				
Dimension	Moderate to large surface area	Higher within-habitat food production; greater carrying capacity	Higher growth and survivorship of fish, especially subadults and adults; higher reproductive rate	Peak flows scour, mobilize, and transport bed material and remove encroaching vegetation; base-flow magnitude determines wetted area of individual riffles and rapids; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to support recovered adult population	Higher food production in system; greater carrying capacity	Same as previous	Peak flows mobilize and transport sediments that form and maintain riffle/rapid habitat and remove encroaching vegetation; base-flow magnitude determines amount of habitat in reach; amount and characteristics of sediment affect erosion and aggradation rates of channel
Intra-annual stability	Relatively stable throughout base-flow period	Higher within-habitat food production; greater carrying capacity	Same as previous	Peak flows scour riffles and rapids and remove encroaching vegetation that might otherwise trap sediment and reduce size making them less stable; sufficient base-flow magnitude maintains habitat area during summer, autumn, and winter; base-flow variability reduces stability of habitat; amount and characteristics of sediment affect erosion and aggradation rates of channel
Bed composition	Low percentage of fine sediment, low embeddedness	Same as previous	Same as previous	Peak flows mobilize bed material and reduce embeddedness; descending limb of the peak flow and base flows winnow fine material from substrate; fine sediments reduce primary production of submergent macrophytes and reduce production of benthic invertebrates; amount and characteristics of sediment affect erosion and aggradation rates of bed
Connected Backwaters				
Dimension	Moderate to large surface area, moderate depth	Higher within-habitat production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish especially juveniles; greater recruitment	Peak flows scour, deepen, and create backwaters; remove encroaching vegetation; base-flow magnitude determines volume of individual backwaters during summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Connected Backwaters (Cont.)				
Amount in reach	Sufficient to support recruitment levels needed for recovery	Higher food production in system; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish especially juveniles; greater recruitment	Peak flows scour, deepen, and create backwaters; remove encroaching vegetation; base-flow magnitude determines amount of habitat available in reach during summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Initial timing of availability	Summer	Early access to productive habitat	Same as previous	Onset of base-flow period determines timing of availability; peak flows deposit sediments that form and determine elevation of habitat, which can affect timing of availability; flows on descending limb of peak flush sediment
Inter-annual availability	Consistent amount and quality of habitat available in system each year	More consistent, higher production in system; greater availability of habitat; greater carrying capacity	More consistent levels of recruitment from year to year	Peak flows scour, transport, and deposit sediments; antecedent conditions (elevation of sediment deposits) affect ability of peak flows to create backwaters in any year; inter-annual variability in base-flow magnitude affects stability among years; amount and characteristics of sediment affect erosion and aggradation rates of channel
Intra-annual stability	Relatively stable throughout base-flow period	Higher within-habitat and system-wide food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish, especially juveniles; greater recruitment	Peak flows create larger and deeper backwaters, which are more stable; base-flow magnitude determines volume of individual backwaters during summer, autumn, and winter; base-flow variability affects stability; amount and characteristics of sediment affect erosion and aggradation rates of channel
Within-day stability	Relatively stable during the day	Higher within-habitat and system-wide food production; greater habitat availability; greater carrying capacity	Same as previous	Peak flows create larger and deeper backwaters, which are more stable; base-flow magnitude determines volume of individual backwaters during summer, autumn, and winter; within-day variability in base flow decreases stability; amount and characteristics of sediment affect erosion and aggradation rates of channel

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Side Channels				
Dimension	Moderate to large surface area, moderate depth	Higher within-habitat production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish, especially juveniles; greater recruitment	Peak flows scour, deepen, and create side channels; remove encroaching vegetation; base-flow magnitude determines volume of individual side channels during summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to support recruitment levels needed for recovery	Higher food production in system; greater availability of habitat; greater carrying capacity	Same as previous	Peak flows scour, deepen, and create side channels and remove encroaching vegetation; base-flow magnitude determines amount of habitat available in reach during summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Initial timing of availability	Summer	Early access to productive habitat	Same as previous	Onset of base-flow period determines timing of availability; peak flows deposit sediments that form and determine elevation of habitat, which can affect timing of availability; flows on descending limb of peak flush sediment
Inter-annual availability	Consistent amount and quality of habitat available in system each year	More consistent, higher production in system; greater availability of habitat; greater carrying capacity	More consistent levels of recruitment from year to year	Peak flows scour, transport and deposit sediments and elevation of antecedent sediment deposits affect ability of peak flows to create side channels in any year; inter-annual variability in base-flow magnitude affects availability among years; amount and characteristics of sediment affect erosion and aggradation rates of channel
Intra-annual stability	Relatively stable throughout base-flow period	Higher within-habitat and system-wide food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish, especially juveniles; greater recruitment	Peak flows create larger and deeper side channels, which are more stable; base-flow magnitude determines volume of individual side channels during summer, autumn, and winter; base-flow variability affects stability; amount and characteristics of sediment affect erosion and aggradation rates of channel

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Eddies				
Dimension	Moderate to large surface area and depth	Higher within-habitat food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship; higher reproductive and recruitment rates	Peak flows create deposits behind which eddies form and remove encroaching vegetation; base-flow magnitude determines volume of individual eddies during summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to support recovered adult population and necessary recruitment levels	Higher food production in system; greater availability of habitat; greater carrying capacity	Same as previous	Peak flows create deposits behind which eddies form and remove encroaching vegetation; base-flow magnitude determines amount of eddy habitat during summer, autumn, and winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Shoreline complexity	High to moderate levels of complexity	Greater microhabitat diversity; greater carrying capacity	Same as previous	Shoreline complexity affected by sediment particle size and channel morphology; peak flows mobilize materials and can affect complexity
Inter-annual stability	Consistent amount and quality of habitat available in system each year	More consistent and higher production in system; greater availability of habitat; greater carrying capacity	More consistent growth, survivorship, and rates of reproduction and recruitment	Peak flows create deposits behind which eddies form and remove encroaching vegetation; inter-annual variability in base-flow magnitude affects stability among years; amount and characteristics of sediment affect erosion and aggradation rates of channel
Intra-annual stability	Relatively stable throughout base-flow period	Higher within-habitat food production, greater carrying capacity	Higher growth and survivorship; higher reproductive and recruitment rates	Peak flows can create larger and deeper eddies, which are more stable; base-flow magnitude determines volume of eddies during summer, autumn, and winter; base-flow variability during year affects stability; amount and characteristics of sediment affect erosion and aggradation rates of channel
Bed composition	Low percentage of fine sediment, low embeddedness	Same as previous	Same as previous	Peak flows deposit fine sediments in eddies; base flows winnow fine material from substrate; fine sediments reduce primary production of submergent macrophytes and reduce production of benthic invertebrates; amount and characteristics of sediment affect erosion and aggradation rates of bed

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Flooded Tributary Mouths				
Dimension	Moderate to large surface area	Higher within-habitat food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship; higher reproductive and recruitment rates	Magnitude and duration of mainstem peak flows determine habitat area; high mainstem peak flows deposit sediments into eddies at mouth; deposits are subsequently eroded by flows from tributary; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to support recovered adult population and necessary recruitment levels	Higher food production in system; greater availability of habitat; greater carrying capacity	Same as previous	Affected by the number of tributaries in reach; magnitude and duration of mainstem peak flows determines area of habitat; amount and characteristics of sediment affect erosion and aggradation rates of channel
Initial timing of availability	Spring	Greater habitat availability	Same as previous	Mainstem peak-flow magnitude and timing determines inundation of habitat
Inter-annual availability	Consistent amount and quality of habitat available in system each year	More consistent and higher food production in system; greater habitat availability; greater carrying capacity	More consistent growth, survivorship, and rates of reproduction and recruitment	Inter-annual variability in peak-flow magnitude and duration affects availability among years; amount and characteristics of sediment affect erosion and aggradation rates of channel
Intra-annual stability	Relatively stable during mainstem peak-flow period	Higher within-habitat production; greater carrying capacity	Higher growth and survivorship; higher reproductive and recruitment rates	Peak-flow variability within a year affects stability
Flooded Bottomlands				
Dimension	Moderate to large surface area and volume	Higher within-habitat food production; better water quality; greater habitat availability; greater carrying capacity	Higher growth and survivorship of fish especially juveniles; higher recruitment rates	Higher peak flows inundate larger areas; very high peak flows can mobilize floodplain sediments, remove vegetation, and enlarge individual habitats; base-flow magnitude can affect water table and size of some habitats (depression wetlands) during summer, autumn, winter; amount and characteristics of sediment affect erosion and aggradation rates of channel

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Flooded Bottomlands (Cont.)				
Amount in reach	Sufficient to support recruitment levels needed for recovery	Higher food production in system; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish, especially juveniles; higher recruitment rates	Higher peak flows produce larger amount of habitat in reach; very high peak flows can mobilize floodplain sediments, remove vegetation, and increase the overall amount of habitat; base-flow magnitude can affect water table and amount of some habitats (depression wetlands) during summer, autumn, winter; amount and characteristics of sediment affect erosion and aggradation rates of channel
Initial timing of availability	Precede and coincide with larval appearance	Greater access to productive habitat	Same as previous	Peak flow timing and magnitude determine inundation of habitat and transport of larvae into habitat
Connection to channel	Provide access to and escapement from habitat at frequencies sufficient to support recruitment levels needed for recovery	Same as previous	Same as previous	Peak-flows maintain connection by scouring, or reduce connection by depositing sediments, depending on the configuration of entrance, allow drifting larvae to enter habitat and older fish to leave habitat, transport nutrients to main channel, and transport non-native fish to main channel; amount and characteristics of sediment affect erosion and aggradation rates of channel
Inter-annual availability	Available in sufficient number of years to support recruitment, with periodic drying to eliminate non-native competitors	More consistent and higher production in system; greater availability of habitat; greater carrying capacity	More consistent levels of recruitment	Sufficiently high peak flows ensure access to floodplains each year; occasional low peak and base flows needed to allow drying; amount and characteristics of sediment affect erosion and aggradation rates of channel

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Flooded Bottomlands (Cont.)				
Intra-annual stability	Retain sufficient water until connection reestablished	Higher within-habitat and system-wide food production; greater availability of habitat; greater carrying capacity	Higher growth and survivorship of fish, especially juveniles; higher recruitment rates	Base-flow magnitude maintains habitat area during summer, autumn, and winter; base-flow variability may reduce stability; amount and characteristics of sediment affect erosion and aggradation rates of channel
Spawning Bar Complexes				
Dimension	Moderate to large surface area; greater habitat complexity	Higher food production in staging portions of complex; greater availability of habitat	Greater concentrations of spawning adults; higher hatching rates and survivorship of embryos; greater production of larvae; higher recruitment rates	Peak flows scour and maintain large complex gravel and cobble bar complexes preferred as spawning areas, remove encroaching vegetation; channel morphology and hydraulics determine deposition patterns and habitat dimension; flow during spawning period determines wetted area of individual habitats within complex; amount and characteristics of sediment affect erosion and aggradation rates of channel
Amount in reach	Sufficient to provide recruitment needed for recovered populations	Same as previous	Same as previous	Channel morphology and hydraulics determine amount and location of spawning complexes within reach; flow during spawning period determines amount of habitat in reach; amount and characteristics of sediment affect erosion and aggradation rates of channel
Initial timing of availability	Spring	Greater availability of habitat	Same as previous	Peak-flow magnitude and timing determines suitability of conditions in complex during spawning period (pre- and post-peak periods)
Inter-annual availability	Consistent amount and quality of habitat available in system each year	More consistent availability and quality of habitat each year	More consistent production of larvae; more consistent recruitment rates	Peak flows scour and maintain large complex gravel and cobble bar complexes preferred as spawning areas, remove encroaching vegetation; amount and characteristics of sediment affect erosion and aggradation rates of channel

Table C.1 (Cont.)

Habitat Type and Characteristic	Preferred Condition	Effect on Biological System	Effect on Endangered Fish	Hypothesized Geomorphic Processes That Affect Habitat Characteristic
Spawning Bar Complexes (Cont.)				
Intra-annual stability	Relatively stable throughout spawning period	Higher food production in staging portions of complex	Better condition of adults; higher hatching rates and survivorship of embryos; greater production of larvae; higher recruitment rates	Peak flows scour spawning habitats and remove encroaching vegetation that might otherwise trap sediment and reduce size of spawning habitats making them less stable; flow variability during spawning period reduces stability of habitat; amount and characteristics of sediment affect erosion and aggradation rates of channel
Velocity	Sufficient to transport fine sediment and oxygenate spawning gravel	Not applicable	Higher hatching rates and survivorship of embryos; greater production of larvae; higher recruitment rates	Magnitude of peak flows (ascending and descending limbs) affects velocity over sediment deposits during spawning and incubation period
Bed composition	Low percentage of fine sediment, low embeddedness	Higher food production in staging portions of complex	Better condition of adults; higher hatching rates and survivorship of embryos; greater production of larvae; higher recruitment rates	Peak flows scour spawning habitats and remove encroaching vegetation that might otherwise trap fine sediment in habitats; base flows winnow fine sediment from spawning areas; amount and characteristics of sediment affect erosion and aggradation rates of bed